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MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

Vol. XCVI.

EDITED BY

JAMES FORREST, Assoc. Inst. C.E., Secretary.

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8, 15 and 22 *January*, 1889.

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SECT. III.—ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

CORRIGENDA.

Vol. xcii., p. 489. Abstract "Fire-Boats." Messrs. Shand, Mason and Company draw attention to the fact that they constructed self-propelling fire-boats as early as 1852. A list of such boats is given in *Engineering*, Jan. 14, 1887.

" xciv., pp. 210 to 230, *passim*, *for* "Dwelshauvers-Dery" *read* "Dwelshauvers-Dery."

" " p. 313, line 21, *for* "1886" *read* "1883."

" xcv., p. 159, line 13, *for* "tyres" *read* "tires."

" " p. 472, line 6 from bottom, *for* "2295" *read* "2925."

" " p. 457, line 6 from bottom, *for* "lime" *read* "calcium chloride."

" " p 489. Abstract "Gadot Accumulators." In the table giving the thickness, height, breadth, and distance apart of the plates, the decimal point should be shifted one place to the left, so as to read "0·228," etc.

" xcvi., p. 131 In the longitudinal section of the Blankenberg Hartz Railway the elevation of Huttenrode should be 477·40 instead of 422·40.

" " p. 132, line 2 from bottom, *for* "2*s*. 0·8*d*." *read* "2*s*. 0·2*d*."

" " " line 1 from bottom, *for* "3·82 marks = 3*s*. 8·7*d*" *read* "3·32 marks = 3*s*. 3*d*."

" " p. 133, line 1, *for* "2*s*. 3·2*d*." *read* "2*s*. 3·8*d*."

" " " line 2, *for* "3·60 marks=3*s*. 6·0*d*." *read* "3·80 marks=3*s*. 8·7*d*."

" " " line 12 from bottom, *for* "Payerbach to Gloggnitz" *read* "Gloggnitz to Murzzuschlag."

" " " line 9 from bottom, *for* "Murzzuschlag to Gloggnitz" *read* "Gloggnitz to Murzzuschlag."

" " Plate IV. The direction of the map in respect of North and South should be reversed.

THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1888-89.—PART II.

Sect. I.—MINUTES OF PROCEEDINGS.

8 January, 1889.

Sir GEORGE B. BRUCE, President,
in the Chair.

The following Associate Members have been transferred to the class of

Members.

William Butterton, Jun.
Thomas William Keele.
Percy Tarbutt.
James Thropp.
Thomas Walker

The following Candidates have been admitted as

Students.

Arthur James Arnot.
John Walter Brown.
Arthur Brownsword.
Percy Nicholson Collyer.
George Reginald Davey.
Harold Deans, B.A.
Stanley Arthur Lane.
Alexander Norwell.
Cecil Onslow Purdey.
Andrew Anderson Puzey.
Charles Edward Simpson.
Joseph Slater.
Charles Melbourne Smith.
Murray Walker.
John Whitelaw, Jun.
William Edward Challoner Wilson.

The following Candidates were balloted for and duly elected as

Members.

Richard Henry Abbatt.
Thomas Parker.

Associate Members.

Earnest Wheatstone Baker.
John Ferguson Bell.
Robert Gordon Blaine, M.E.
George Blair, Jun., Stud. Inst. C.E.
Hugh Meller Bradford, Stud. Inst. C.E.
Philip Bright, Stud. Inst. C.E.
Henry Darlington Cable.
Dugald Clerk.
Henry Bedwell Fisher.
Hugo Robert Ford.
Alexander Farquharson Fowler, Stud. Inst. C.E.
Levy John Groves.
Henry Leonard Hinnell, Stud. Inst. C.E.
Alfred Moser Hiscocks.
Reginald William James, Stud. Inst. C.E.
Frederic Lobnitz.

Associate Members—continued.

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Henry Ward Middlemist.
Hugh McPherson Mitchell, Stud. Inst. C.E.
Frank Fearne Neall.
Frederick Oscar Oertel, Stud. Inst. C.E.
William Parker.
Petley Lloyd Augustus Price.
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John Clark Ross.
Arthur John Simpson.
Henry Edwin Simpson.
Ernest Albert Stickland.
Edward Richmond Stokoe, Stud. Inst. C.E.
James Thomson
Herbert Frederick Tomalin.
David William Trail Valentine.
Beresford Verschoyle.

Associates.

William George Margetts.
Charles Hubback Watson.

(*Paper No. 2364.*)

"The Compound Principle applied to Locomotives."

By Edgar Worthington, B.Sc., Assoc. M. Inst. C.E.

The primary object of the various attempts which have been made during the last thirty-six years, and more especially within the last ten years, to apply the compound principle to locomotive-engines, is to expand the steam in the cylinder more than is commonly done at present, and thus to save fuel. The following advantages, which will be discussed hereafter, are claimed for compound locomotives:—

The use of higher steam-pressures. A more powerful locomotive. Additional power at starting. Reduction of the wiredrawing action as the steam passes through the slide-valve, especially with early cut-off. Obtaining all the available power from the expanding steam, and thus discharging the exhaust-steam into the atmosphere at as low a pressure and temperature as possible. More even distribution of strains in the moving parts, and consequently a more uniform turning effort at the crank.

The realization of these advantages would no doubt be a valuable achievement, and any one, observing the violent exhaust of the modern locomotive, may safely conclude that there is room for improvement in some, if not in all, of these directions. The average modern locomotive burns from 3 to 5 lbs. of coal per indicated HP. per hour, compared with about 2½ lbs. the amount consumed by a good non-condensing land engine, notwithstanding that the locomotive type of boiler is more economical than the Cornish or Lancashire type frequently used with land engines.

Before considering this subject of coal consumption in compound engines, it may be interesting to call to mind some of the

best results obtained from the ordinary or single-expansion locomotive. The results brought before the Institution by Mr. W. Stroudley, M. Inst. C.E.,[1] are perhaps among the most complete obtainable. The express engine "Gladstone" took a load of twenty-three vehicles, weighing, with engine and tender, 335 tons 14 cwt., from London to Brighton, burning 24·87 lbs. of coal per mile. The average speed was 43·3 miles per hour, and the average HP., computed from a complete set of indicator diagrams taken each mile, was 528·53. From this it is calculated that not more than 2·04 lbs. of coal were burnt per indicated HP. per hour. Mr. Stroudley adds that about 2 per cent. of the water used was condensed exhaust-steam. This is a phenomenal performance seldom equalled in daily practice. It surpasses the results calculated from Mr. Mallet's and Mr. F. W. Webb's experiments in both simple and compound locomotives (Table II). But comparing it with the non-condensing compound portable engines exhibited at Newcastle in 1887,[2] working with about 140 lbs. steam-pressure, the same pressure as the Gladstone locomotive, it will be found that the portable engine burnt 1·99 lb. per brake HP. per hour, which is 0·05 lb. less than the locomotive's indicated HP. per hour. This seems to suggest that in the best locomotives there is room for only 2½ per cent. economy of fuel by the adoption of the compound principle.

From a series of tests, extending over three months, on an express engine of the Philadelphia and Reading Railroad, about the year 1884, results were obtained showing the coal consumption per indicated HP. per hour to be 3·55 lbs. Again, the trials last year of the Strong locomotive, on several railroads of the United States, show a consumption of 4 lbs. of coal per indicated HP. per hour with a boiler-pressure of 160 lbs. Exact results of the work done by locomotives in England are not readily obtained, owing to the varying weights of the trains; but, without introducing more figures at present, it may be assumed that the usual coal consumption of locomotives is from 20 to 50 per cent. more than that of non-condensing land engines.

In Table II will be found an extraordinary instance of the saving of a portion of this wasted fuel, namely, a comparison between Mr. Mallet's compound engines on the Bayonne and Biarritz Railway in 1879, and some other simple engines doing similar work. Both

[1] Minutes of Proceedings Inst. C.E., vol. lxxxi., Tables VII and VIII, p. 106.

[2] Journal of the Royal Agricultural Society of England. Second Series. vol. xxi., 1887; also Table V.

engines working at their maximum power, the simple engine would burn 4·9 to 5·5 lbs. of coal per indicated HP. per hour, but the compound engine burnt 3·3 to 3·52 lbs., showing a saving of 35 per cent. in favour of the compound locomotive.

Large cylinder-capacity, with high boiler-pressures and early steam cut-off, has been tried by Mr. S. W. Johnson, M. Inst. C.E., of the Midland Railway, and other locomotive engineers, as a means of obtaining that economy which results from working steam expansively. But such attempts seem to overtax the capacity of the link-motion. Express locomotives at high speeds require an early release to enable the cylinders to exhaust their steam freely, or, in other words, to avoid what is sometimes called "smothering" the cylinders; but the Author has often noticed that, when simple engines are run with a very high expansion, the large ends of the connecting-rods get hot, owing, perhaps, to the great amount of friction due to the unavoidable steam-compression in the cylinder on the return stroke. Consequently the driver is obliged to lengthen the stroke of the valve, and use more steam, which causes a great drain upon the boiler. A second difficulty in the ordinary link-motion, when working steam at high degrees of expansion, is the too early release of the steam at low speeds. These two properties of the link-motion have rightly been considered excellent qualities for ordinary service; but when carried to high degrees of expansion, the distribution of steam in the cylinder is affected in such a way as to produce wiredrawing and internal strains in the machinery, also to cause the valves to jump from their faces.

Wiredrawing is perhaps the most serious objection to the link-motion at high speeds and high expansion. It occurs chiefly during the admission of steam to the cylinder, when the edge of the valve does not open the port wide enough to admit sufficient steam to fill the space behind the rapidly-advancing piston. The use of the double-ported, or Allen slide-valve, overcomes this difficulty to some extent; but indicator diagrams taken from locomotives at speeds above 20 miles per hour show a marked difference between the boiler and the initial cylinder-pressures, amounting in some cases to 30 lbs., part of this being due to the resistance of the steam-pipe, and part to the throttling action of the slide-valve. The irregularity of the steam-admission line clearly appears in Plate 1, Figs. 1 and 6. This latter circumstance has been pointed out by Mr. D. K. Clark, M. Inst. C.E., who, in 1850, showed that it was practically impossible, with economy, to cut off steam earlier than one-third stroke, owing to wiredrawing during admission.

It may, therefore, be concluded that the ordinary best-designed

link-motion is not suitable for effecting, at high grades of expansion in one cylinder, that distribution of steam which shall produce the greatest possible effective pressure on the piston. An ordinary locomotive, using steam at 120 lbs. pressure per square inch, could not be run at high speeds for any great distance with 40 per cent. of steam cut-off, without loss of boiler-pressure; but with higher pressures and efficient early steam cut-off, the same boiler would supply steam to perform an equal amount of work with ease during any reasonable period. Several systems of valve-gear claim to produce a better distribution of steam than the link-motion, but the problem of making any substantial improvement with a single valve still remains to be solved. On the Continent double slide-valves have been employed, by Meyer in Bavaria, and Guinotte in Belgium; also by Polonceau and others. Of late years, American locomotive engineers have endeavoured to obtain this desired high expansion in a single cylinder, by introducing improved forms of the multiple-valve system, as follows:—

Mr. W. Wilson, of the Chicago, Alton, and St. Louis Railroad, has applied a motion operating double valves to locomotive-engines, with encouraging results. Mr. Alex. Mitchell, Lehigh Valley Railroad, and others, have Mr. Strong's locomotives at work, which operate separate admission and release-valves by an ingenious but complicated motion derived from one eccentric. Mr. A. J. Stevens, of the Central Pacific Railroad, has experimented with a special motion operating a valve at each end of the cylinder. These arrangements may, however, be laid aside for the present, as being too complicated for ordinary use.

By adopting the compound principle, the highest needful degree of expansion can be obtained without subjecting the steam to the early cut-offs and wiredrawing rendered necessary by the same degree of expansion in a single cylinder.

It is not the object of the present Paper to discuss at length the behaviour of steam during its expansion within the cylinders. This has been done recently, and most exhaustively, by Mr. P. W. Willans, M. Inst. C.E.[1]

But, before proceeding to consider in detail the compound principle in locomotive-engines, the Author will refer to one or two general principles bearing on the subject. In the simple ideal indicator diagram, Plate 1, Fig. 10, where the expansion-line, for the sake of simplicity, has been constructed according to Boyle's law, it

[1] Minutes of Proceedings Inst. C.E., vol. xciii. p. 128.

will be seen that although the production of 1 lb. of steam at 200 lbs. pressure per square inch requires only 1·3 per cent. more heat than that required to produce 1 lb. of steam at 100 lbs. pressure, yet 36·9 per cent. more power is obtainable from the 1 lb. of steam at 200 lbs. than from that at 100 lbs., if they be both expanded to the same exhaust pressure, namely, 20 lbs. That is, neglecting the influence of condensation and temperature during expansion, $\frac{100}{101\cdot3} \times 36\cdot9$ = 36·4 per cent. more power is available from steam at 200 lbs. than from steam at 100 lbs. This is due to the latent heat in the two cases being practically a large constant quantity, and the additional heat required to produce the high-pressure steam a small amount, which is directly employed in increasing the steam-pressure. Practical experience confirms the inference to be drawn from this consideration, namely, that within certain limits depending upon other conditions, the higher the pressure of steam supplied to a steam-engine, the greater will be its duty.

On the other hand, steam at 200 lbs. is not so readily produced as at 100 lbs., because its temperature increases with increased pressure. In the above ideal example, Plate 1, Fig. 10, the total heat necessary to produce 1 lb. of steam at 100 lbs. pressure per square inch from water at 32°, according to Mr. D. K. Clark, is 1,184·5 heat-units. And to produce 1 lb. of steam at 200 lbs. pressure per square inch is, according to the same authority, 1,200 units. The temperature of the former is 338° Fahrenheit, and of the latter 388°, a difference of 50°. That is to say, the difference of temperatures of the steam and water in two boilers, producing respectively steam at 100 lbs. and 200 lbs., is 50°; but, as the temperature of the hot gases is much above that of the water in the boilers, the flow of heat from the fire through the fire-box plates and tubes will not be much affected by this slight difference in temperature of 50° in the two boilers. Thus the little extra heat expended in producing steam of the higher pressure has developed a considerable increase in the available work.

But another action goes on in the cylinder, namely, cooling. Whilst steam is expanding it cools; and when in contact with metal of a different temperature, especially with a wet surface, it either parts with its heat rapidly and becomes condensed, or takes up more heat and expands. If steam at 180 lbs. per square inch be expanded in one cylinder down to atmospheric pressure, the temperature of the walls of that cylinder will remain intermediate between 379°·7 and 212°, the respective temperatures of steam at these two extreme pressures.

During the first portion of this forward stroke of the piston, the actuating steam, being warmer than the cylinder walls, condenses and loses its pressure; and, during the latter part of this stroke, the remaining steam, being slightly cooler than the walls of the cylinder, absorbs heat, and a portion of the condensed steam is re-evaporated. This re-evaporation occurs in all unjacketed cylinders, and is especially noticeable in the indicator diagrams of slow-moving engines working with an early cut-off; it will be seen that the re-evaporation occurring during the latter part of the forward stroke is not entirely useless, because it increases the pressure during that portion of the stroke. But the far greater re-evaporation during the backward or exhaust stroke, when the damp spent steam is at or near 212°, results in a dead loss; because heat thus absorbed does no useful work, but is simply carried away from the cylinder walls. The temperature of these walls will thus be approximately

$$\frac{\frac{379^\circ{\cdot}7 + 212^\circ}{2} + 212^\circ}{2} = 253^\circ{\cdot}9.$$

In other words, steam at, say, 180 lbs. pressure and 379°·7 is suddenly admitted to a cylinder at 253°·9, and instantly begins to condense and lose its pressure. During the latter half of the forward stroke the water of condensation is re-evaporated into steam, which action continues during the return or exhaust stroke, extracting heat from the warm cylinder, which remains at the completion of the revolution at its original temperature of 253°·9 Fahrenheit. In the above instance, the cylinder is supposed to be well protected from cooling by radiation, but not to be superheated by a steam-jacket.

If, on the other hand, steam at 180 lbs. be expanded through two cylinders on the compound system, with a receiver-pressure of 80 lbs., then the temperature of the high-pressure cylinder would

$$= \frac{\frac{379^\circ{\cdot}7 + 324^\circ{\cdot}1}{2} + 324^\circ{\cdot}1}{2} = 338^\circ,$$

and the temperature of the low-pressure cylinder

$$= \frac{\frac{324^\circ{\cdot}1 + 212^\circ}{2} + 212^\circ}{2} = 240^\circ.$$

Thus the average temperature of the high-pressure cylinder would be 98° above that of the low-pressure cylinder. Condensation and

re-evaporation would still go on in each of these cylinders. But the steam at 180 lbs. pressure would, in one case, enter a warm high-pressure cylinder at 338°, and in the other a cool single cylinder at 253°·9, there being a difference of 84°·1 in the temperatures of the two cylinders in favour of the high-pressure one. The chilling action of the exhaust-steam at 212° would no longer be felt in this small cylinder, so that work would be developed in it before much steam could be condensed. The final exhaust-steam could only draw heat from the low-pressure cylinder, the temperature of which would be 240°; whereas, in the ordinary engine before named, the single cylinder was maintained at the higher temperature 253·9°, thus having more available heat to be extracted and wasted by its exhaust-steam. It will also be noticed that the whole of the heat absorbed from the high-pressure cylinder by re-evaporation during the latter half of the forward stroke, and the whole of the return stroke of the high-pressure piston, would be utilized in maintaining the pressure in the low-pressure cylinder. From this point of view, therefore, less heat would be thrown away by re-evaporation in engines built on the compound system than in ordinary engines. The same reasoning might be applied to triple- and quadruple- expansion engines.

It would be difficult to prove the above points individually in practice; but the general and successful adoption of steam-jacketing where it is possible, on engines working through long ranges of expansion, goes far to confirm the correctness of this principle. The effect of the steam-jacket on cylinders should be to add fresh heat to the steam at every step of its expansion, and thus prevent condensation. It should be remembered, however, that steam passes so rapidly through the cylinders of locomotive engines, that the phenomena above described occur to a less degree there than in the cylinders of slower moving engines.

Large single-cylindered stationary engines with Corliss, or other automatic cut-off valve-gear, are worked to very high degrees of expansion as economically as smaller cylindered compound engines of equal power. But these devices are not applicable to the modern locomotive with its high steam-pressure, its ever varying conditions and frequent reversals.

Very high grades of expansion are used in compound condensing engines. Mr. L. A. Riedinger exhibited such an engine at Nuremberg in 1883, which worked with twelvefold expansion. And high-pressure marine, triple or quadruple expansion, condensing engines could be made to work economically with 200 to 250 lbs. boiler-pressure, up to twenty-five fold.

But the extremes of very early cut-off and multiple expansion in triple or quadruple cylinder engines are beyond the scope of practical locomotive engineering, where the limits of working have hitherto been found to lie within an eightfold expansion and two cylinders, Plate 1, Figs. 1, 3 and 5. Some engineers maintain that anything in excess of a fivefold expansion in locomotives must result in disappointment, and that even with this ratio some amount of superheating between high-pressure and low-pressure cylinders would be desirable, if not necessary; but the indicator diagram, Plate 1, Fig. 3, represents an eightfold expansion with a residual pressure of about 8 lbs. In slow-moving engines, with well jacketed cylinders, it is frequently advantageous to use a tenfold expansion for steam at 160 lbs. pressure above the atmosphere, the steam being in these cases exhausted at a pressure of about 2½ lbs. The same steam, after a fivefold expansion, retains 20 lbs. pressure. But simple adiabatic expansion cannot be obtained in a locomotive, owing to losses of pressure by condensation and re-evaporation, the former action being much intensified by radiation and convection of heat from the engine.

Considering the unsuitability of the link-motion for earlier steam cut-offs than 30 per cent., there appears to be no other alternative in approximating to a theoretical tenfold expansion, than by passing the steam through two cylinders in succession, which is known as the compound system. The Author has taken several indicator diagrams from compound locomotives working with an eightfold expansion, and these showed that very little pressure remained in the exhaust-steam from the low-pressure cylinder. Diagrams taken with greater expansions often showed a partial vacuum towards the end of the stroke of the low-pressure cylinder. It may thus be inferred, both from a theoretical and from a practical point of view, that an eightfold expansion is about the limit of working steam in a locomotive, and that a fivefold expansion would be more suitable for high speeds, where steam throttling and the chilling action of the cylinders are more active.

Both land and marine compound engines are usually fitted with a condenser and air-pump, which cannot conveniently be carried on an ordinary locomotive. The Author is aware of only two instances in which locomotives have been worked with air-pumps to maintain a vacuum, both of these being tramway-engines, one having a spray-condenser with surface-water cooler, built for the Birmingham Central Tramway Company, and the other having an ordinary air surface-condenser, from which the air-pump extracted the condensed water. A considerable vacuum and some

fuel economy were obtained in these cases; but the additional number of parts and joints necessary to maintain the vacuum complicated the engines, already overloaded with machinery, and the use of a vacuum has been recently abandoned.

In mill and marine engines so little power is required to start the shafting, or the propellers, respectively, that a very slight effort is sufficient to move the engine over its centres or other awkward starting positions; and when once started a marine-engine may run for days, or even weeks, with a nearly uniform load; whereas a locomotive at rest, with cranks standing in any position, is suddenly called upon to exert its maximum tractive power in starting a train. Since the working conditions of locomotives are so different from those of land or marine engines, it cannot be assumed that, because compounding has been beneficial in marine engines, a compound locomotive must necessarily be more economical than a simple locomotive. While bearing this in mind, it may be interesting to glance at the economical results obtained in compound marine engines.

Table II, compiled from various sources, shows some average results of fuel consumption in single, double, triple and quadruple-expansion engines, ranging from the year 1867 to the present time. It will be noticed that ocean mail-boats, notwithstanding their increased boiler-pressure, are not now much more economical than the Pacific Steam Navigation Company's steamers of twenty years ago. This is due to the high engine-speed, small cylinder-capacity, and severe duty of modern mail-steamers. It is, however, worthy of note that the ordinary boats show much improvement of late years, especially those worked on the principle of triple and quadruple expansion.

The performances of some simple and compound locomotives and land engines have been worked out, and placed in Table II, from which it is evident that locomotives are a long way behind in the scale of economy. Compounding marine engines was commenced less with the intention of obtaining greater steam expansion and increased economy than of dealing with the increased pressure and piston-speed rendered necessary by crowding the engine into the smallest possible space to obtain more cargo-carrying capacity, thus augmenting its power without increasing the size of its low-pressure cylinder.

Triple expansion has met with great success in modern marine engines,[1] as is well illustrated by the comparative working of

[1] Transactions of the North-East Coast Institution of Engineers and Shipbuilders, vol. iii., 1886–87, p. 229.

eleven double-expansion and nine triple-expansion engines at sea, where the latter effected an average saving of 25·38 per cent. over the double-expansion engines. Quadruple-expansion marine engines, with boiler-pressures as high as any locomotive carries, have also been successfully tried, and, although the friction of four engines must be considerably more than that of two or three, yet the employment of piston-valves in the steam-yacht "Myrtle" has rendered possible the construction of quadruple-expansion engines, which absorb only $8\frac{1}{4}$ per cent. of the power of the engine in friction, while they develop 1 indicated HP. for every 1·2 lb. of best picked Welsh Penrikyber coal consumed (Table II). The diameters of these four cylinders are respectively 12, 17, 24, and 34 inches, and the common stroke 24 inches. Another yacht, the "Grace Darling," indicates 360 HP., with cylinders $10\frac{1}{4}$, 14, 20, and 28 inches in diameter, all having a stroke of 20 inches. Thus the compound marine engine has been developed economically from the double-expansion engines of the Pacific Steam Navigation Company of twenty years ago, using steam at 40 lbs. pressure, and burning $2\frac{1}{2}$ lbs. of coal per indicated HP. per hour, into the modern cargo-boats, using steam at 180 lbs., and burning $1\frac{1}{2}$ lb. of fuel per indicated HP., and the "Myrtle," with each HP. requiring 1·2 lb. of best coal. The gradual, but rapid, advance in the use of high-pressure steam in the British Navy is graphically shown by Plate 1, Fig. 31; and although the difficulties of lubrication, and making joints at such high pressures as are now used, may stay the upward progress of this curve, yet it is not likely the maximum pressure has yet been reached. It may be some time before practical engineers follow the example of Messrs. Everard and Jenks, Philadelphia, U.S., who constructed an experimental boiler and engine which the Author saw seven years ago, working successfully with a steam-pressure of 400 lbs. per square inch.

The compound system has found very wide and successful application in mill engines, but the triple-expansion system, advocated by Sir William Fairbairn and others as long ago as 1868, has not been adopted in this class of engine, in which the boiler-pressure seldom exceeds 80 to 100 lbs. per square inch.

History.—It is now proposed to take a brief historical survey of the various types of compound locomotives hitherto built, and subsequently to discuss more minutely the advantages and disadvantages of the system as applied to locomotive engines.

The earliest attempt to apply the compound principle to the locomotive was made by the late Mr. James Samuel, M. Inst. C.E.,

in 1852, when he designed a "continuous-expansion steam-engine."[1] It should be remembered that locomotives had but a short time previous to this been worked with steam cut-off at $\frac{2}{3}$ $\frac{3}{4}$ of the stroke. Mr. Samuel at that time enunciated the following simple but important principle: "The greatest useful effect is obtained from the steam, when it is allowed to expand in the cylinder, until its pressure upon the piston just balances all the useless resistances of the friction of the engine itself, and the resisting pressure on the back of the piston." He endeavoured to attain this end by admitting steam to one cylinder only, expanding a portion of this steam through a second cylinder working a crank at right angles to the first, and using the remainder of the exhaust from the first cylinder as a blast. He claimed that this method gave a more uniform turning-effort on the crank, and a saving of 20 per cent. in fuel over the usual method of working expansively. A goods engine on the Eastern Counties Railway, when altered to this system, saved 12 lbs. of coke per mile, when performing the same amount of work as before the alteration.

After this, the idea of expanding steam through more than one cylinder seems to have slumbered, until it was awakened by Mr. Jules Morandière, who in 1866 designed a three-cylinder compound locomotive, having one high-pressure cylinder and two low-pressure cylinders, but he did not work it out in detail; and the three-cylinder locomotive was forgotten, to be brought out in another form fifteen years later by Mr. F. W. Webb, M. Inst. C.E.

Meantime Mr. Anatole Mallet, being thoroughly impressed with the theoretical advantages of compounding, was developing his two-cylinder compound locomotive, the first of which was made at Creusot in 1876 for the Bayonne and Biarritz Railway. After several years of experimenting, Mr. Mallet showed, at the Paris Exhibition of 1878, a six-wheel coupled tank-engine, Plate 2, Fig. 16. It is arranged to work either simple or compound by simply moving an ordinary slide-valve placed on the side of the smoke-box. This "distributing" or "starting slide-valve" is shown in Plate 3, Fig. 38. It covers three ports, the middle one being the exhaust from the high-pressure cylinder, and the others, on either side, leading respectively to the low-pressure steam-chest and the blast-nozzle. This valve can thus distribute the high-pressure exhaust steam either to the low-pressure chest in order to work compound, or direct to the blast-nozzle. In the latter case an automatic reducing-valve, Fig. 38, admits boiler-steam to the dis-

[1] Institution of Mechanical Engineers. Proceedings, 1852, p. 27.

tributing valve-box, whence it passes through the above-mentioned side port into the low-pressure valve-chest. Mr. Mallet arranged his reversing-gears so that the steam cut-offs in the high-pressure and low-pressure cylinders were independent. From these and other compound locomotives on the Haironville Railway, the Paris and Orleans, and the Northern Railway of Spain, good results were obtained, and described by him in 1879.[1] Mr. Mallet also designed a four-cylinder compound locomotive, with one high-pressure and one low-pressure cylinder, placed tandem, and controlled by one valve-motion, on each side of the engine, there being an equilibrium stop-valve to act as both regulator and starting-valve. For engines of large power he has more recently advocated the plan of placing the four cylinders in pairs, the high-pressure pair working on a set of four or six coupled wheels, and the low-pressure pair on another similar set of wheels. Mr. Mallet has also designed a triple-expansion high-speed locomotive, having one 18-inch cylinder and three cylinders 26 inches in diameter.[2]

Other French engineers have taken considerable interest in the development of the compound locomotive, including those connected with the Northern, Paris, Lyons and Mediterranean, the Western and the Orleans Companies.

In 1878, Mr. Webb converted an old outside-cylinder Trevithick passenger engine, having 15-inch cylinders and wheels 6 feet in diameter, into a compound engine (Plate 2, Fig. 15) by reducing the diameter of one of the cylinders to 9 inches, and retaining the other as a low-pressure cylinder. He fitted the engine with a starting slide-valve answering the same purpose as Mr. Mallet's valve, and the engine ran light passenger-trains on a branch line with very encouraging results.

In 1881, Mr. Webb constructed the first of his three-cylinder compound locomotives, the "Experiment," his main objects being to attain economy in fuel, and to utilise the adhesive weight of two pairs of wheels without the use of coupling-rods. The steady running and economical results obtained from this engine, on the Irish and Scotch mail trains, were such that Mr. Webb built other similar engines, increasing the high-pressure cylinders from 11½ inches to 13 inches in diameter. In May 1884, he compounded one of the Metropolitan condensing tank-engines, and in the same year constructed the first of a class of more powerful express-engines,

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[1] Institution of Mechanical Engineers. Proceedings, 1879, p. 328.

[2] *Ibid.* Proceedings, 1886, p. 374.

named "Dreadnought" (Plate 2, Fig. 25), now used in working the heaviest passenger traffic on the London and North Western Railway.

In the following year he compounded a double-ended side-tank passenger-engine (Plate 2, Fig. 26), and in 1887, an eight-wheeled side-tank engine (Plate 2, Fig. 27). As all of these types have been constructed on the same principle, one of the latest forms of the "Dreadnought" class is alone described. This engine weighs 42 tons, 10 cwt. It comprises two outside high-pressure cylinders 14 inches in diameter, and 24 inches stroke, and one inside low-pressure cylinder 30 inches in diameter, and 24 inches stroke. There are thus three distinct engines, each actuated by Joy's valve-gear. The two high-pressure engines have their slide-valves placed underneath the cylinders. The latter are attached to the outside frame-plates immediately below the side foot-plates, about midway between the smoke-box and the middle wheels, and act through their piston-rods and connecting-rods upon the trailing wheels. The single low-pressure cylinder has its slide-valve on the top, and is placed midway between the frames immediately below the smoke-box. Its connecting-rod takes hold of a single-throw crank on the axle of the middle pair of wheels. The boiler is worked at 180 lbs. per square inch, and the steam is conducted from an equilibrium regulator in the dome to a brass T pipe fixed to the smoke-box tube-plate, and thence by two copper steam pipes $3\frac{3}{4}$ inches in diameter, running first parallel with the tube-plate, then through the back-plate which carries the low-pressure cylinder, and between the inside and outside engine-frames, to the steam-chests of the high-pressure cylinders. The exhaust-steam from each of these cylinders is returned in a copper pipe 5 inches in diameter, running horizontally beneath the high-pressure pipe, into the smoke-box. Each pipe then passes through the hot gases, round the smoke-box to the opposite side, and enters the steam-chest of the low-pressure cylinder. Thus the high-pressure exhaust-steam, at a pressure restricted by means of a safety-valve to 80 lbs. per square inch, becomes superheated or dried in these pipes by the waste gases of the smoke-box, while the large capacity of the pipes obviates the necessity for a separate steam receiver. The final exhaust escapes through the back of the low-pressure slide-valve and steam-chest cover into the blast-pipe, and thence to the chimney in the usual way, the only difference being that the number of exhaust-beats for urging the fire is reduced to half compared with an ordinary engine. One of the pipes, forming the receiver in the smoke-box, is fitted with a valve, Plate 3, Fig. 29,

similar in construction to the regulator, and opening direct into the blast-pipe, which allows the driver to turn the receiver steam directly from the high-pressure cylinders into the chimney, a course which may be useful in starting, should the low-pressure crank stand on a dead-centre. An ordinary screw-valve, Plate 3, Fig. 39, placed on the side of the smoke-box, enables the driver to admit a small amount of boiler high-pressure steam into the receiver to start the low-pressure crank when it is not on a dead-point. These two starting valves are ingeniously arranged to work with two distinct motions of one handle, the arrangement being such that the first may be locked open to the chimney while the second remains shut. Balanced slide-valves are used in all three engines. The low-pressure cylinder-cocks are fitted with safety-valves, to prevent the pressure rising above 80 lbs. per square inch; and an automatic air-valve is placed on the receiver to open when the engine is running without steam, in order to destroy the vacuum, which would otherwise form in the receiver and act as a retarding force in the large cylinder, Plate 1, Fig. 9. The reversing-gear consists of a hand-wheel and screw, connected to the middle of a short lever, the ends of which are joined by long stiff rods to the high-pressure and low-pressure reversing-shaft. Thus the two high-pressure and the one low-pressure engines can be reversed together; or, by a simple means of locking either high-pressure or low-pressure, the other gear can be adjusted by the hand reversing wheel to the required amount of "notching up," or steam cut-off required.

Three-cylinder compound locomotives on the same system have also been constructed for the following railways: Western Railway of France; Paulista Railway; Antofagasta Railway, South America; Oudh and Rohilkhand Railway; Austrian State Railways; San Paulo Railway, Brazil; Western of Buenos Ayres Railway; Pennsylvania Railroad.

On the 19th of May, 1885, one of the largest of this class of engine took the 10 a.m. train from Euston to Carlisle. The average load including engine and tender was 207 tons, and the average speed, including stoppages, 44·7 miles per hour. The fuel consumed was 29·2 lbs. per mile; 9·49 lbs. of water were evaporated per lb. of coal. On this occasion Shap incline, a long grade of 1 in 75, was ascended at the rate of 33 miles per hour, during which the HP. developed in the three cylinders was 810. On the 27th of March, 1885, a similar engine drew a train weighing 292 tons, 15 cwt., including engine and tender, from Liverpool to Crewe, at the rate of 43·4 miles per hour.

The three-cylinder type of engine is well adapted to large-power locomotives, inasmuch as it is not necessary to crowd the cylinders between the frames, nor to have a large low-pressure cylinder overhanging on one side of the engine. There would be no difficulty in building such an engine with much larger outside high-pressure cylinders, and the whole of the space between the frames is available for the one large low-pressure cylinder. In this respect there is no limit to the cylinder power of this type of engine.

In 1885, Mr. T. W. Worsdell, M. Inst. C.E., of the Great Eastern Railway, constructed a number of four-wheels coupled compound express locomotives (Plate 2, Fig. 20), having two inside cylinders, 18 and 26 inches in diameter respectively, working in the ordinary manner on a crank-axle coupled to a trailing-axle. Two years later Mr. Worsdell, having become Locomotive Superintendent of the North Eastern Railway, constructed some similar express-engines for the latter railway; and about the middle of 1887 a compound goods engine (Plate 2, Fig. 21), which, being the latest development of this type, it is proposed to describe more in detail. In outside appearance this engine is neat, simple, and substantial. It weighs 40 tons, 7 cwt., and has six coupled wheels 5 feet 1¼ inch in diameter. The cylinders, which are 18 and 26 inches in diameter, and 24 inches stroke, are placed as in the passenger compound engines beneath the slide-valves, and inside the frames. The chief features of this goods engine to be observed are the starting and intercepting valves, which enable the engine-driver to start the engine by admitting sufficient high-pressure steam to the large cylinder, without interfering with the small cylinder, in case the latter is not in a position to start the train alone. The two valves are operated by steam, and controlled by one handle. They are illustrated in Plate 3, Fig. 40. If the engine does not start when the regulator is opened, which will occur when the high-pressure valve covers both its steam-ports, the driver pulls the additional small handle, which closes the passage from the receiver to the low-pressure cylinder, and also admits a small amount of steam to the low-pressure steam-chest, so that the two cylinders together develop additional starting-power. After one or two strokes of the engine, the exhaust-steam from the high-pressure cylinder automatically forces the two valves back to their normal position, and the engine proceeds working compound.

Through the kindness of Mr. Worsdell, the Author has been enabled to travel on one of these North-Eastern compound engines, with a stopping goods train, when he observed that, in shunting operations, the auxiliary valve, supplying steam to the low-pressure

cylinder, had to be used on about every alternate occasion of starting, but in no case was there any delay in the prompt starting of the locomotive. Mr. Worsdell's engines, both passenger and goods, work the East Coast Scotch traffic, much of which is over a level line, but there is at least one severe grade of 1 in 96 for 4 miles. They are also being introduced on several railways in India and in South America.

In the year 1880, two of Mr. Mallet's compound locomotives were built in Germany for the Hanoverian State Railways, to the designs of Mr. von Borries, who in the same year improved upon Mr. Mallet's engines, by connecting the two valve-motions to one reversing-shaft, and by so arranging the diameters of the cylinders, the angles of the reversing-shaft arms, and the length of expansion-link hangers, that the steam cut-off in the two cylinders was such as to develop an almost equal amount of work in each engine at all positions of the reversing-lever in forward gear, thus relieving the driver from any responsibility as to the work done by each cylinder. Mr. von Borries' starting-valve, introduced about 1885, answers the same purpose as Mr. Worsdell's, and is shown in an improved form in Plate 3, Fig. 41.

In October, 1887, there were seventy-eight compound locomotives of the von Borries' type in Germany. Some of these are goods and some passenger engines; but a short description of the express passenger engines (Plate 2, Fig. 18), built in 1885–86, will suffice to give an idea of the type of compound engine so successfully used on the German State Railways. They have four wheels coupled, and outside cylinders $16\frac{1}{2}$ and $23\frac{5}{8}$ inches in diameter respectively, and $23\frac{7}{8}$ inches stroke, placed like Mr. Webb's high-pressure cylinders about midway between the leading and the front coupled wheels. Mr. von Borries claims that this arrangement causes the engine to run very steadily. The hind wheels are thus the drivers, and are coupled to the middle pair by rods. These wheels are 6 feet $1\frac{1}{4}$ inch in diameter. Between the two cylinders is placed a receiver, containing the automatic starting-valve. The slide-valves are on the top of the cylinders, and are worked by the Walschäert gear, the reversing-shaft passing over the top of the boiler. This arrangement would expose the steam-pipe and receiver to much cooling wind and radiation if they were not carefully cased. The system of superheating the receiver-pipes in the smoke-box, though applied to the German goods engines, is not adopted in these passenger engines. The weight of the engine in working order is 37 tons 8 cwt., and it draws with great economy the express trains running across the comparatively flat plains of Germany, where, through the kindness

of Mr. von Borries, the Author had an opportunity of observing its steady running in September 1887.

Mr. F. Schichau has designed and constructed a number of light four-wheel coupled outside-cylinder tank compound locomotives in Germany, one of which was shown at the Amsterdam Exhibition in 1883 (Plate 2, Fig. 17). These engines are worked with an ordinary regulator, and if the position of the cranks is such that steam must be admitted to the low-pressure cylinder to start the engine, this is done by the regulator-handle opening a port which conducts boiler-pressure steam through a small pipe, fitted with a reducing-valve, into the intermediate receiver. This steam, by assisting the large piston and impeding the small one, effects a gradual start. These engines are said to start well, though the absence of an intercepting valve causes the starting effort to be less than that of the von Borries or Worsdell engines, where the steam admitted to the receiver acts only on the low-pressure piston.

On the Northern Railway of France, after some experience with compound engines, one with four cylinders was constructed in January 1886 (Plate 2, Fig. 28). This engine has one pair of high-pressure and one of low-pressure cylinders working on separate axles. The system ensures an even tractive power, plenty of opportunity for expansion, and practically no limit to the size of the cylinders. On the other hand, it is expensive and heavy, having four cylinder castings instead of two.

In 1883, Mr. Underhill, superintendent of motive power of the Boston and Albany Railroad in the United States, constructed a tandem four-cylinder compound locomotive, by placing two small high-pressure cylinders in front of the two ordinary cylinders using low-pressure steam. As far as the Author is aware, this is the only instance hitherto of a compound locomotive being worked in the United States. Shortly afterwards, in 1884, this engine was given up, because it proved more expensive to maintain than the simple engine, without showing a corresponding economy. The compound system is, however, to have another trial at the hands of Mr. Ely, M. Inst. C.E., superintendent of motive power of the Pennsylvania Railroad, who is obtaining one of Mr. Webb's three-cylinder locomotives.

Mr. Borodin has constructed and successfully worked since 1881 a compound locomotive in South Russia. Trials have also been made in India by Mr. Charles Sandiford, M. Inst. C.E.,[1] both of two-cylinder and four-cylinder compound locomotives (Figs. 29 and 30),

[1] Institution of Mechanical Engineers. Proceedings, 1886, p. 297.

which have been followed by orders for further and more extensive trials of the system.[1] Two-cylinder compound engines on the Worsdell and von Borries system have been designed by Sir A. M. Rendel, M. Inst. C.E., for India; and several types have been designed for South America, all of which have been built in this country.

Table I contains a list of about five hundred and sixty-nine compound locomotives, at present working or under construction, with their principal dimensions.

Having taken a hasty glance at the various types of compound locomotives, the Author proposes to discuss some of the principles involved in the construction of their details, the ultimate object being to discover how to obtain the greatest amount of work from the expanding steam, and to convert that work into a uniform propelling force with as little strain and friction as possible in the parts of the machinery.

In designing compound engines, it is generally advisable to arrange the proportions of the cylinders so that the combined effort exerted by them is as continuous as possible. Mr. Samuel, in 1852, claimed as the chief advantage of his continuous expansion engines, that the moving power was less irregular than that exerted either by the single cylinder or by the Woolf or tandem compound engine. And he pointed out that although a greater amount of theoretical economy, due to expansion, can be obtained from either of these last two types when expanding to the extreme limits than in his continuous-expansion engine, yet in his engine there was a greater uniformity of effort, and therefore expansion could practically be carried to a considerably greater extent. In marine and stationary engines, the ratio between the volumes of high-pressure and low-pressure cylinders is about 1 to 4, which is much greater than in locomotives. But this is due to the adoption of a condenser, comparatively slow speeds, and long continuous runs, which allow the steam to be expanded to a much greater extent than in the locomotive.

Mr. Mallet has experimented, perhaps more than any one else, on the best proportion of cylinder for compound locomotives. It will be seen from Table III that he has constructed or rebuilt engines with the low-pressure cylinder 1·71 the capacity of the high-pressure cylinder; and he has increased this proportion by degrees up to 2·78 times. His conclusions, expressed in 1883, are that the low-pressure cylinder should have a volume at least double

[1] Institution of Mechanical Engineers. Proceedings, 1886, p. 355.

that of the high-pressure cylinder, which is confirmed by Mr. von Borries and Mr. Worsdell's practice, and by his own more recently expressed opinion. Mr. Webb adopts the larger cylinder ratio of 2·25 or 2·30 to 1, without inconveniently crowding the cylinders, and is thus enabled to obtain a higher ratio of expansion for the steam.

It is difficult to give any theoretical formula for the right proportion between these cylinders, owing to the cooling by convection and radiation, and to the following points which the locomotive constructor must consider, but which have little influence on the snugly placed steam-jacketed cylinders in stationary or marine engines. A cylinder of very large diameter cannot easily be placed by the side of another cylinder, between the frames of a locomotive, without cutting a hole in one of the frames, which is objectionable. An outside cylinder of large diameter is, perhaps, even more undesirable, as it widens the engine, and places in their worst position those disturbing momentum forces, which are greater in the large or low-pressure engine, than in the small or high-pressure engine. This objection does not hold to the same extent with the three-cylinder type of engine, where there is ample space for one large low-pressure cylinder between the frames. In Table III will be found several examples of locomotives already constructed, together with the relative volume of their high-pressure and low-pressure cylinders. In most cases this has been regulated by the diameter of the cylinders alone; but some engineers prefer to obtain the required volume by varying the stroke instead of the diameter, thus obtaining the same capacity of cylinder with a more convenient piston. Mr. Webb has made use of this method in his side-tank passenger engine, where the diameter of the cylinders are 14 and 26 inches, and the strokes 18 and 24 inches respectively. In 1888 compound engines were constructed in Germany with the two cylinders of equal diameter, but the stroke and therefore the piston speed of the low-pressure was made double that of the high-pressure cylinder. This method is therefore not applicable to high-speed engines.

When the cylinder capacity is determined, the work developed on each side should be equalized under all conditions of pressure and valve-gear. To solve this problem, the early constructors of compound locomotives arranged separate reversing-gears for each cylinder, so that the driver might discover by practice the best positions in which to work the engines. Mr. Mallet has always preferred to make the point of steam cut-off in each cylinder variable, and he therefore employs two independent reversing-

gears. Mr. Webb's ingenious single-screw reversing-gear, which allows the steam cut-off in both high-pressure and low-pressure engines to be adjusted independently, has already been described, and in practice the low-pressure engine is usually kept nearly in full gear, while the notching up for expansion is carried out in the high-pressure engine.

Mr. Borodin fixes the cut-off in the low-pressure cylinder at 70 to 73 per cent., and varies the speed of the engine by adjusting the high-pressure cut-off and by the regulator.[1] Mr. von Borries adopts the following simple method of obtaining approximately equal power from high-pressure and low-pressure cylinders, at all stages of forward gear.[2] In the ordinary curved link-motion he makes the lifting links of different lengths, the difference being about $\frac{1}{20}$ the total lift of the expansion-link. This gives a later cut-off in the low-pressure cylinder as shown on Table IV.

In the Allen or straight link-motion a similar result, Table V, is obtained, by placing the reversing-shaft arms at judicious angles.

In other types of valve-gear, such as Brown's, Joy's, &c., the same proportion of mean cut-off may be obtained by placing the two radial links at an angle with each other, of about $\frac{1}{20}$ of the total angle through which the links swing. Mr. Worsdell arranges the forward gear of his passenger engines to cut off the steam in the low-pressure cylinder about 20 per cent. later than in the high-pressure cylinder, and thus succeeds in equalizing the power derived from the two cylinders. But in Sir A. M. Rendel's ten-wheel engines, Plate 2, Fig. 19, he provides only a 10 per cent. difference of cut-off in the two cylinders in forward gear.

There is one manifest objection to this simple method of permanently fixing the valve-motion in order to specially suit the forward gear, namely, that the back gear is unavoidably changed for the worse. In ordinary engines, both goods and passenger, this is not an important objection; but the method is inapplicable to shunting-engines, or tank-engines which run frequently in back gear. In these engines neither the length of the lifting links, nor the angles of the reversing-shaft lifting arms, should be altered, and the engine will therefore have equal steam cut-offs in both small and large cylinders. Thus in Mr. Schichau's tram engine, Plate 2, Fig. 17, the point of cut-off in the two cylinders is always the same.

[1] Institution of Mechanical Engineers., Proceedings, 1886, p. 297.

[2] "Compound-Lokomotiven," A. von Borries. Glaser's Annalen. Berlin, vol. xix. p. 174. 1886.

The tractive power of a compound locomotive required to maintain a train at full speed on its steepest gradient is not always the maximum it may be called upon to exert. On most of the railways in this country, it is considered that if an engine can start a train it can take it through the whole journey. Mr. J. W. Barry, M. Inst. C.E., stated, in his fifth lecture delivered before the School of Military Engineering at Chatham in 1877, that the friction of rest in oiled axle-boxes is sometimes as much as 22 lbs. per ton.[1] The same tractive power exerted upon a well-cared-for vehicle in motion would maintain it at a speed of 50 miles per hour on the level. All locomotives should therefore be able to exert at starting their full tractive power. In the Worsdell and the von Borries types of compound locomotives a special starting valve is provided, enabling the engine to exert more power during its first revolutions than afterwards when in motion. Tram engines, Fig. 24, constructed on this principle start with ease, although possessing but $\frac{4}{5}$ the tractive power of simple engines working similar traffic. There are certain positions in the three-cylinder compound engine when the high-pressure axle only is available for starting; but as a superabundance of power is brought to bear upon this one axle, owing to the absence of back pressure in the receiver, the use of sand beneath the tread of the wheels may enable the engine to start at all times with a very heavy load.

The tractive power of two-cylinder or three-cylinder compound engines may be calculated by the same principles as are applied to ordinary engines. But in each case the high-pressure and the low-pressure engines must be treated separately. To construct a two-cylinder compound engine of a power equal to an ordinary engine, Mr. von Borries recommends that the high-pressure cylinder be made the same size as one of the simple engine cylinders, and that the low-pressure cylinder should be double the capacity of the high-pressure cylinder, the boiler-pressure being at the same time increased 1 to 2 atmospheres. Compound engines, built on these principles, have dealt successfully in Germany, England, South America and India, with ordinary traffic previously worked by simple engines; but when called upon at slow speeds to exert their maximum power, either in accelerating speed or in ascending inclines with a heavy load, the simple engine is found to be more powerful. Comparing an ordinary engine with a compound engine having a high-pressure cylinder, the same size as one of the ordinary engine cylinders, and a low-pressure cylinder double its capacity,

[1] Railways and Locomotives, 1882, p. 204.

if both these engines work slowly with the same steam-pressure, 175 lbs., and the same maximum steam cut-off, say, 75 per cent., then, comparing the ideal expansion diagrams (Plate 1, Figs. 11 and 12) of these two engines working at their maximum power, it will be seen that the compound engine can only exert about 74 per cent. of the power of the ordinary engine. If the boiler-pressure of the compound engine be 25 lbs. more than that of the simple engine, then the ideal diagrams, Plate 1, Figs. 13 and 14, represent the maximum power in each case, from which it will be seen that the maximum available power of the compound engine is about 89 per cent. of that of the simple engine. A compound engine must therefore not only use higher steam-pressure, but also have larger cylinders, to enable it to exert the same power as an ordinary engine. Mr. Charles Sandiford converted an old engine on the 5 feet 3 inches gauge, having cylinders 15 inches in diameter, into a compound engine by increasing the size of the cylinders to 18 inches and 24 inches in diameter, and he thus obtained from the latter, on a level line in India, decidedly more power than from the original simple engine. The Author is therefore inclined to think that the high-pressure cylinder of a compound locomotive should be made about 1 inch larger in diameter than one of the simple cylinders of an equally powerful ordinary engine. The following is a simple method of calculating the size of cylinders in a compound engine to possess the same maximum power at slow speed as an ordinary engine with 17-inch by 24-inch cylinders and a 6-inch wheel.

Simple Engine.

Boiler-pressure = 150 lbs.

Two cylinders 17 inches diameter, 24 inches stroke. Diameter of wheels, 6 feet.

Effective cylinder pressure = $c \times$ boiler-pressure, then—

$$\text{Tractive power} = \frac{17^2 \times 24}{72} \times c \times 150$$
$$= 14{,}450 \times c.$$

Compound Engine.

Boiler-pressure = 180 lbs.

Intermediate pressure = 70 lbs.

Stroke = 24 inches. Diameter of wheels = 6 feet.

Let x = diameter of high-pressure cylinder, then tractive power

$$= \frac{1}{2}\,\frac{x^2 \times 24}{72} \times c \times 110 + \frac{1}{2}\,\frac{2\,x^2 \times 24}{72} \times c \times 70 = x^2 \times 42\,c;$$

that is, $14{,}450\,c = x^2 \times 42\,c$,

$$x^2 = \frac{14{,}450}{42} = 344,$$

$$x = 18\tfrac{1}{2} \text{ inches} = \text{diameter of high-pressure cylinder},$$

$$\sqrt{2 \times 18\tfrac{1}{2}^2} = 26\cdot 1 \text{ inches} = \text{diameter of low-pressure cylinder}.$$

Perhaps this method of estimating the diameters of compound-locomotive cylinders may give slightly too large a result; for the average effective pressure in both the high-pressure and low-pressure cylinders may approximate nearer to the maximum effective pressure therein than in the simple engine, without running the risk of drawing fire through the tubes by a too violent blast. But careful experiment is the only satisfactory method of settling this question, and the experience gained from compound locomotives on several railways, including the Buenos Ayres and Rosario Railway, tends to confirm the opinion, that the high-pressure cylinder should be made about 1 inch larger in diameter than the cylinders of an ordinary engine of equal power, even though an advance of 30 lbs. per square inch of boiler-pressure be contemplated for the compound engine.

At very great speeds, where high expansive working is essential, compound engines use the steam more efficiently than simple engines, and under these circumstances appear to greater advantage than in the above slow speed comparison. Indicator diagrams have been taken from Mr. Webb's engine, Fig. 25, showing over 1,000 HP., and Mr. Worsdell's passenger engine, with its ordinary average train, indicates 911 HP. at 60 miles per hour. An examination of the diagrams, Figs. 42, 43, 44 and 45, all of which are taken from locomotives running at about 250 revolutions per minute, will throw light on this point without further comment.

The next subject to be examined is the danger in steam passages. It is observed, even in the best express locomotives, that the steam-chest pressure seldom rises to within 15 to 20 lbs. of the boiler-pressure, when the engine is running fast. This is due to the incapacity of a long and tortuous steam-pipe to supply the cylinder's large and intermittent demands. In compound engines the evil effect of thus wiredrawing the steam may easily be doubled, and even quadrupled. In the compound engine the steam has to pass through at least double the distance, and round many more bends than in a simple engine; and again, there is not so much pressure behind the steam to carry it through these passages, to the large cylinder where the initial pressure (when working a

light train) may be as low as 20 to 30 lbs. per square inch, instead of the boiler-pressure in the ordinary engine. It has been urged by some locomotive engineers that a steam-pipe of 1-inch diameter is sufficient to drive a locomotive. This may be true at slow speeds; but for quicker-running engines the difference between a 3-inch and a $3\frac{3}{4}$-inch steam-pipe has been shown by Mr. Webb to be very greatly in favour of the larger pipe. There is not much difficulty in making the small cylinder steam-passages of ample size; but it is otherwise in a large cylinder of say 26 inches or 30 inches diameter. In an ordinary locomotive-engine, the area of the steam-port is about $\frac{1}{10}$ the area of the piston, though in France and elsewhere 0·07 is a ratio more frequently adopted. To maintain this proportion with a cylinder 30 inches in diameter would necessitate an unwieldy valve, or a very long valve-travel. When it is also considered that the pressure of the steam, as it enters the large cylinder, is often less than 50 lbs., whereas in the ordinary engine it may be 112 lbs. per square inch, it is evident that the steam-passages in the former cylinder should be further enlarged, to avoid sacrificing a large percentage of the available pressure in propelling such a volume of steam through small ports and passages. Applying the above principle to a low-pressure cylinder 30 inches in diameter, the area of steam-port should be $\frac{120}{50} \times \frac{1}{10} = 0 \cdot 24$ time the area of the piston, that is $169\frac{1}{2}$ square inches, requiring a valve of enormous dimensions.

The boldest step in constructing low-pressure cylinders has been taken by Mr. Webb, who has built many 26 inches and 30 inches in diameter. The steam-passages of the latter have been increased in later engines. Their sectional area is now $49\frac{1}{2}$ square inches at the valve-face, or 0·07 of the piston area. The area through the body of the passages is 0·078 of the area of piston, though where these two steam-ports enter the cylinder they are somewhat contracted. Mr. Webb has lessened the obstructions to the exhaust-steam in narrow passages by taking it in a direct course through the back of the slide-valve, which lies on the top of the cylinder, and thus conducting it in a straight line up the blast-pipe.

The most detrimental steam wiredrawing is, however, at the edge of the slide-valve; and as the low-pressure valves in compound locomotives must necessarily be very short compared with the diameter of their cylinders (the ports of cylinders 26 inches in diameter are in some cases only 14 inches long), the Allen, or double-ported, valve has been used to double the effective length of the steam-admission port. Mr. Worsdell and Mr. von Borries

adopt this class of valve for large cylinders; Mr. Webb adopts it for small or high-pressure cylinders. Triple-ported slide-valves, giving a line of steam admission three times the length of the valves, have been used in triple expansion marine-engines, but not in locomotives. Although in Mr. Mallet's compound engines the steam has to traverse many circuitous and narrow passages, yet he found, in 1883, that the engine was well adapted for high speeds.[1] The steam-ports of slow moving goods-engines need not be so large as those of passenger-engines running at high speeds. But the tendency of the present day, in this country, is no doubt to run fast goods trains.

It is not the intention of the Author to go over the well-worn arguments relating to the capacity of the receiver of a compound engine, but simply to indicate the difference between the requirements of a receiver in the two-, three-, or four-cylinder locomotives.

The receiver-capacity of a two-cylinder compound locomotive, having its cranks at right-angles to each other, should be not less than the capacity of the small cylinder; for it must be capable of containing at least one-half the small cylinder full of steam, discharged during the latter part of the stroke of the low-pressure cylinder, when the latter is not taking steam, as well as the steam which was left in the receiver after the previous stroke. In Mr. Webb's engine the small cylinders and the large cylinder work independently of each other, and the supply of steam to the receiver is nearly constant, being delivered four times per revolution from the high-pressure cylinders, instead of twice, as in the case of two-cylinder compound engines. Four-cylinder locomotives of the tandem or Woolf type, in which each high-pressure cylinder discharges its exhaust-steam directly into the corresponding low-pressure cylinder, have as small a receiver-capacity as possible. But engines with four independent cylinders require about the same receiver-capacity as two-cylinder engines.

Table VI shows the relative receiver-capacity in certain compound locomotives now running. Mr. Charles Sandiford, who constructed a four-cylinder compound locomotive in India,[2] first with a very small receiver-capacity, and second with receiver-pipes passing round the smoke-box, found the latter to be an improvement, giving drier steam and steadier pressure in the low-pressure cylinder. On the other hand, a large amount of steam bottled up

[1] Institution of Mechanical Engineers. Proceedings, 1883, p. 446.
[2] *Ibid.*, 1886, p. 255.

in the receiver has caused inconvenience with some compound locomotives, including tram engines, which have been required to stop and start frequently. The receiver should be well protected from the atmosphere by jackets of air, silicate cotton, felt, or other non-conducting substance, and a portion or the whole of the receiver may with advantage consist of copper pipes passing round inside the smoke-box, where the steam can be revived and dried, as in Mr. Webb's, Mr. Worsdell's, and most modern compound locomotives.

The indicator diagrams, Plate 1, Figs. 1 to 9, give a fair idea of the behaviour of steam in some of the above-named classes of compound locomotives. Most of the diagrams have been taken at slow speeds, in order to eliminate the throttling influence of the steam-passages; and they thus illustrate more clearly the principle of compounding in locomotives. They have been reduced to a scale of 80 lbs. to the inch, and both high-pressure and low-pressure diagrams have been combined in the usual way, which shows what amount of available power has been realized.

The largest amount of work would be obtained from the expanding steam in a compound engine, if the cut-off in the low-pressure cylinder were permanently fixed at a point where the volume of steam admitted would be equal to the capacity of the high-pressure cylinder. Thus, in a compound engine whose cylinder capacity was 2 : 1, the steam cut-off in the low-pressure cylinder would be at 50 per cent. of the stroke, and in Mr. Webb's engines it would be about 42 per cent. of the stroke of the low-pressure cylinder. If this theoretical cut-off were adopted, the unenclosed triangular area A (Plate 1, Figs. 2 and 5), below the theoretical expansion curve, shown on some of the combined diagrams, would be included in the lower diagram. This advantage, however, must be sacrificed. For it is more important to arrange the low-pressure cut-off so as to divide the work equally between the two cylinders. A well-designed locomotive, having a cylinder ratio of 2 : 1 or 2·1 : 1, would probably expand its steam to most advantage with a cut-off of 30 per cent. in the high-pressure and 40 per cent. in the low-pressure cylinder. The diagrams taken at speeds such as Plate 1, Figs. 1 and 6, show a space between the two, caused partly by the resistance to the steam passing round the numerous passages of the receiver, but largely by the narrowness of the steam-port openings. The same wiredrawing agency is observable in the high-speed diagram, Plate 1, Fig. 8, on comparing it with Fig. 7 taken at a slow speed.

It is maintained by some theorists that most of the loss indicated by the triangular area A, and the fall of pressure in the receiver,

is recovered in the superheating action caused by the steam expanding into the receiver without doing visible work. But this self-heating, if appreciable, is equivalent to but a slight diminution of the pressure, and it seems likely that the greater portion of the energy, spent during this reduction of pressure, is absorbed in forcing the heavy damp steam through small passages. The regenerative heat, imparted to the moist steam in the receiver, is of great value, not only in drying the steam, but also in raising the temperature of the low-pressure cylinder, and thus diminishing the condensation which necessarily takes place in that large unjacketed casting.

The advantages of the compound system applied to the locomotive engine may be arranged under three heads.—

I. A saving of fuel and water, due to the use and easy manipulation of high steam-pressures and large ratios of expansion.

II. A more uniform distribution of pressure on working parts, when running, than in the ordinary locomotive.

III. An increased power of starting a train.

I. Sir Frederick Bramwell, Past President Inst. C.E., and Mr. William Anderson, M. Inst. C.E., have declared that careful trials of non-condensing compound engines "appear to point to the conclusion that, with our present state of knowledge, it is probable that pressures between 150 lbs. and 200 lbs. per square inch will give the best practical results."[1]

Steam-pressures of 175 lbs. per square inch are now used in locomotives by Mr. Webb, of the London and North Western Railway, Mr. Johnson, of the Midland Railway, Mr. Underhill, of the Boston and Albany Railroad, U.S., Mr. Strong, of New York, and many others, among whom may be mentioned Mr. Lauder, who employs balanced slide-valves on locomotives for very heavy passenger trains in New England, and who believes that boilers could be made with safety to carry 200 lbs. per square inch; and also Mr. von Borries, who reports that the use of the same pressure (12 atmospheres or 176 lbs.) has not resulted in any inconvenience,[2] but, on the other hand, that the boilers so worked will last longer owing to the reduced consumption of fuel and the gentler blast required to maintain steam. Messrs. Marshall and Co., of Keighley, constructed triple-expansion semi-portable engines using

[1] *Journal of the Royal Agricultural Society of England.* Second series, vol. xxiii. p. 699.

[2] "Compound-Lokomotiven." A. von Borries. Berlin, 1886.

175 lbs. per square inch. Mr. Worsdell, on the North Eastern Railway, adopts 170 lbs. per square inch in his compound locomotives; and 180 lbs. is the pressure adopted for the new steam-boats of the White Star Line.

It has been pointed out that the use of high-pressures in one cylinder, with a single slide-valve controlled by any ordinary valve-gear, is attended, at high speeds, by much loss of pressure, caused by throttling and condensation of the steam. Therefore pressures of 150 to 200 lbs. are worked most economically either by independent steam- and exhaust-valves, as in the Corliss engine, by double slide valves, employed on the Central Pacific Railroad since 1883; or, if ordinary locomotive valve-gears be used, the steam must be expanded through more than one cylinder; that is to say, the locomotive must be compounded.

Some statistics, showing the fuel consumption of compound locomotives, are gathered together in Table VII, and in most instances are compared with those from ordinary engines doing similar work.

From this Table it will be seen that an average saving of 18·8 per cent. is effected in fuel by the substitution of compound for ordinary engines. In nearly all of the above instances, the boiler-pressure was higher in the compound than in the ordinary engine.

The following minor advantages may be classed under this head:—

1. Prolonged expansion of steam in one cylinder is avoided; the high-pressure steam develops the first portion of its work in a very hot cylinder, and the latter portion in a cooler cylinder.

2. Re-evaporation is not so great as in an ordinary engine. Condensation takes place chiefly in the cool low-pressure cylinder, and very little heat is abstracted by re-evaporation from the high-pressure cylinder.

3. Leakage at the pistons is reduced, the effective pressure per square inch on each piston being small.

4. High grades of expansion can be frequently used, without the wiredrawing action attending an early steam cut-off.

5. The wear and tear of the boiler is less, notwithstanding the higher pressure.

6. The force of the blast is lessened, and fewer sparks are drawn through the tubes and thrown from the chimney.

II. Under the second class of advantages, namely, the better distribution of pressure on the working parts, when running, the

boiler may first be considered. This is required to evaporate only 80 to 85 per cent. of the water necessary for an ordinary engine to do the same work; and thus, of two boilers of equal size, the one on a compound engine is not driven so hard, and will, therefore, last longer, than the other on a non-compound engine. For using higher pressures a stronger boiler is, however, necessary. Unstayed flat surfaces, and wagon tops with a low factor of safety, must, therefore, be carefully avoided.

In running ordinary locomotives, it is difficult to persuade engine-drivers to work the steam expansively. The frequent consequence is, that a boiler cannot supply sufficient steam unless it is "hard driven." A driver might be compelled to expand the steam by increasing the lap of the slide-valve to, say, 1½ inch; but the engine would not then start well in some positions. This difficulty is avoided by compounding, which on the one hand compels a certain amount of expansion, and on the other allows more than double the expansion possible in the ordinary engine.

The blast-pipe can be made ¼ inch or ⅜ inch larger in diameter, and, the beats of exhaust being lighter and reduced to half their previous number, the tearing action of the blast is diminished, especially at high speeds.

The pressure on the piston, and consequently the working strains throughout the machinery, are more uniform when steam is expanded through two cylinders, than when the same ratio of expansion takes place in one cylinder. This is evident from the indicator diagrams (Plate 3, Figs. 32, 33, and 34), where the shaded areas indicate the pressures actually transmitted by the pistons of a compound and of a simple locomotive respectively, both working at about the same speeds, and with the same ratio of expansion, namely, three times. The two former of these Figs. have been reduced from indicator diagrams kindly given to the Author by Mr. Worsdell. They were taken simultaneously from an express compound engine. Fig. 34 is reduced from an indicator diagram shown by Mr. W. Stroudley.[1] The varying thrust in the connecting-rods of these three engines is shown in Plate 3, Fig. 35, from which it will be seen that the maximum strain occurs in the simple engine, while an equal amount of work is developed in each of the compound cylinders, and distributed more evenly throughout the whole stroke of the piston and revolution of the crank.

Plate 3, Fig. 36, shows that the effort on the crank-pin of the

[1] Minutes of Proceedings Inst. C.E., vol. lxxxi. Plate 6.

low-pressure engine is more uniform than the similar effort of the ordinary simple engine. It is interesting to follow these strains to the crank-pins, and to compare the effect in each case on their wear. It is a well-known law that friction between two surfaces varies as the pressure, and also as the amount of motion between them. Now, in simple engines working with high expansion (Plate 3, Fig. 34), the pressure on the piston at the beginning of the stroke is greater than in the compound engine (Plate 3, Figs. 32 and 33). This is the portion of the stroke when the progress of the piston is small, and the crank is doing the least amount of useful work; therefore, in a simple engine the increased pressure at the beginning of the stroke, while creating a corresponding increase of friction on the crank-pin, causes very little extra useful effort. Again, the sustained pressure during the stroke of the compound engine is advantageous, because in the middle of the stroke nearly all the pressure is transformed to useful effort, and a relatively small proportion is lost in friction. Comparisons of this crank-pin friction are shown in Plate 3, Fig. 37, and the principle involved may be thus briefly stated: work absorbed by friction varies with the travel of the crank, but useful work varies with the travel of the piston. Strain diagrams, similar to Plate 3, Figs. 32–37, but based on a higher grade of expansion than 3 to 1, would show the strains and friction to be still more favourable to the compound principle. Thus, in addition to the evil of throttling caused by very early steam cut-off in a simple engine, there is also this greater amount of crank-pin friction, and greater maximum pressure in all working parts.

When at work, the effective pressure per square inch on the back of compound-engine valves is less than that on the valves of ordinary engines, inasmuch as the sum of the pressures on the high-pressure and low-pressure valves cannot together exceed the boiler-pressure. But the full boiler-pressure, and consequently heavier strains, are brought to bear upon the high-pressure valve and machinery, both when the locomotive is starting, and at other times, when the high-pressure and low-pressure engines are worked independently with prime or boiler-pressure steam admitted to the cylinders by means of the various automatic and non-automatic starting-valves in use for that purpose. Mr. Webb has taken advantage of these reduced working strains in designing his 6 feet 6 inches compound engines, by making the valve-motion extremely light. The total weight of the three sets of Joy valve-motion is here only 284 lbs., in twenty-nine pieces; whereas the total weight of two sets of link valve-motion in his standard simple engine is

793 lbs., in twenty-four pieces (reversing shafts not being taken into account).[1] These lightly built compound engines are not, however, intended for the extremely heavy work performed by the ordinary engines, with which they are here compared. The lightness of their moving parts is rendered possible by the independent action of the two driving axles, either of which will slip round before its parts are overstrained.

The more uniform distribution of strains in compound locomotives enables them to run with exceptional steadiness. This result, however, may be partly due, in the German and in the three-cylinder compound engines, to the position of the cylinders, which are placed far back near the middle of the wheel-base, where their disturbing influence is little felt; and also to the position of the large central low-pressure cylinder, the disturbing forces of which, though great, lie on the centre line of the locomotive.

The advantages derived from the foregoing considerations, regarding the distribution of strains in compound locomotives, may be summarized as follow:—

1. The boiler is less "hard driven," or may be reduced in size.

2. The more uniform pressure on the pistons causes less friction and strain in the moving parts.

3. Slide-valve friction is reduced, causing less wear and tear of valve-gear.

III. The third source of advantage to be considered, namely, the increased power of starting a train, belongs only to those compound engines fitted with one of the intercepting or starting valves, two of which in general use, Plate 3, Figs. 40 and 41, have been noticed in describing the various types of compound engines. The effect of these valves is to admit steam to both cylinders direct from the boiler, and at the same time to prevent this steam, so admitted to the large cylinder, from acting as back pressure on the small piston. It is evident that a large increase of tractive power may thus be exerted at starting, which is useful in overcoming the friction of rest in the axle-boxes of a long train.

Most compound marine, stationary, and portable engines are provided with a supplementary hand-valve for letting a small amount of steam into the low-pressure cylinder, and thus helping the engine over the dead points of the small cylinder until the latter receives steam. But this device, though sufficient for engines which have seldom to overcome large resistances at starting,

[1] Institution of Mechanical Engineers. Proceedings, 1883, p. 441.

is insufficient for a locomotive, which is often required to exert its greatest pull when starting a train on an incline or a sharp curve. A compound locomotive must therefore be capable of exerting power in both cylinders; and this must be done without introducing constructive difficulties, or complicating the drivers' duties. The following methods have been in use:—

1. Designed and constructed by Mr. Mallet, Plate 3, Fig. 38, described p. 12.

2. Designed and constructed by Mr. Webb, in which either the hind axle alone starts the train, or steam is supplied to the receiver in the usual way, Plate 3, Fig. 39, described p. 15.

3. Designed and constructed by Mr. von Borries, Plate 3, Fig. 41, referred to p. 17.

4. Designed and constructed by Mr. Worsdell, Plate 3, Fig. 40, described p. 16.

Several other valves answer the same purposes as the above; but these four are typical starting or intercepting valves, and have been in use for some time.

It is right, however, to say that there are several disadvantages attending the compound system as applied to locomotives. Some of the following are merely minor difficulties which skill and experience may lessen or remove.

The adoption of high-pressure steam is attended by the following drawbacks: the boiler and all steam-joints must be more carefully made. Only the better kind of lubricants are admissible, such as are not decomposed at the higher temperatures of this steam. The gland-packings must be constructed to withstand heat, for which purpose several systems of metallic packing have given good results.

For using very high-pressure steam in compound engines, it has been suggested that the first cylinder, which would be small, should be made of gun-metal or steel, because high-pressure steam corrodes cast iron. Until suitable piston-valves have been invented for the high speeds required by locomotives, these increased steam-pressures may be dealt with by balancing the ordinary slide-valves, a practice successfully carried out in American locomotives for the last eight years, and which is being revived in this country by Mr. Webb.

A moderate amount of drying and superheating of the steam in compound-engines, as it passes from the high-pressure to the low-pressure cylinder, is conveniently accomplished in the smoke-box, and no doubt tends to raise the pressure in the large cylinder; but

experiments on the Chicago, Burlington, and Quincey Railroad, some years ago, tend to show that superheating steam, to such an extent as to increase its pressure, is not economical, as it causes difficulty in lubricating, as well as expense in providing superheaters.[1] Judging from the economical results in recent quadruple-expansion marine engines, it is anticipated that the triple-expansion system might be attended by economy in the locomotive; but the necessary multiplication of parts, and the varied conditions under which a locomotive works, render the application of this system extremely complicated, and it is not necessary, therefore, to further discuss the subject.

Large cylinders, though required by ordinary locomotives, if a high degree of expansion is to be attained, are an essential feature of the compound system. They are cumbersome, and have more cooling surface than small compact cylinders. Much valuable heat may be lost if the large cylinder is not carefully protected by wood, felt, or air-jackets.

A large quantity of water of condensation may be observed in the chimney, thrown from the blast-pipe of the large low-pressure cylinder. At each end of this cylinder Mr. Webb and Mr. Worsdell place safety-valves, which relieve it of any undue pressure caused by the accumulation of water. This large cylinder may also be drained by cutting a groove in the low-pressure cylinder cocks, about $\frac{1}{16}$ inch wide, to allow a constant leak of the condensed water.

The amount of heat lost through radiation and convection, even by the carefully constructed portable engines competing under cover at the Newcastle Exhibition 1887, varied from $3\frac{1}{2}$ to $16\frac{1}{2}$ per cent. of the total amount of heat generated. In a locomotive, owing to its rapid motion through the air, the loss from this cause must be very considerable; therefore any increase in the size or number of exposed hot parts is a distinct disadvantage.

The momentum of a piston, 26 inches or 30 inches in diameter, together with that of the other reciprocating parts of the large engine, causes severe strains, which must be provided for. The difference in weight between the moving parts, on the high-pressure and low-pressure sides, renders it difficult to balance these revolving and reciprocating parts correctly, by counterweights placed in the wheels of outside-cylinder compound engines. The balance-weights in the wheels, in spite of the different theoretical requirements

[1] Report of the American Railway Master Mechanics' Association. St. Paul, Minn. June, 1887.

of the high-pressure and low-pressure engines, are often made equal.

Those compound engines which have more than two cylinders, connecting-rods and valve-gear, have a corresponding additional number of joints and wearing parts, and therefore require more oil than ordinary engines. In the two-cylinder compound system, Plate 3, Figs. 32–37, it has been shown that the pressure on the moving parts is not so great or fluctuating as on the corresponding parts of a simple engine; and it might therefore be expected that the compound engine would need less lubrication than the simple one. This, however, does not appear to have been confirmed in practice. Whether it is due to the use in the compound engines of higher steam-pressures, or to the extra oiling given to a new and less understood class of machinery, it is difficult to say; but several instances have come under the Author's notice, in which two-cylinder compound locomotives have required more oil than simple engines doing similar work. Thus, the result of a carefully observed month's working on the Buenos Ayres and Rosario Railway showed that a compound engine used 11 per cent. more oil than the simple locomotives running the same trains.

Again compound engines, running between Paris and Lille, are said to use a little more oil than the other engines,[1] as also does the four-cylinder compound on the Sind, Punjab and Delhi Railway.[2] A compound tram engine, with cylinders 8 inches and 14 inches in diameter, running journeys $6\frac{3}{4}$ miles long, uses 4·17 pints of lubricating oil and 0·52 pint of cylinder oil per 100 miles.

The degree of expansion must not be carried to such an extent as to exhaust the steam at atmospheric pressure, for then the advantage of the blast, so important a discovery in the early development of the locomotive, would be lost. A reduction of the number of exhausts, from four to two per revolution, may also detract from the power of the blast, especially at very low speeds. But each blast comes from a cylinder double the volume of those in a simple engine, and the boilers of compound engines, if made the same size as those of ordinary engines of similar power, need not be driven so hard. The amount of blast required and the resistance to be overcome in forcing the low-pressure steam through the exhaust passages fix the limits of expansion. Mr. von Borries recommends that the top of the blast-pipe should be cylindrical for

[1] "Revue Générale des Chemin de Fer," May, 1887.

[2] Institution of Mechanical Engineers. Proceedings, 1886, p. 355.

4 inches of its length, to enable the steam to escape in a vertical direction.

In the three-cylinder type of locomotive the low-pressure engine works on an independent axle, and develops an irregular propelling power, which is felt throughout the train at starting; but, as soon as a moderate speed is attained, the pulsations, which correspond to each stroke of the low-pressure piston, have little appreciable effect, the momentum of the train being great.

The two-cylinder compound engine draws steam from the boiler intermittently, only twice per revolution. This disturbs the water in the boiler, where the rising steam tends to carry more moisture along with it through the regulator when flowing irregularly than when drawn in an almost uniform stream to supply the demands of two separate cylinders, as in an ordinary engine. The boiler of a compound-engine should therefore have an ample amount of steam space.

There is a danger in "over-cylindering" a compound engine; for, when running with a light load, such an engine might be obliged to expand its steam to below atmospheric pressure. On the other hand, with the 4-foot 8½-inch gauge, the difficulty of placing the two cylinders between the frames limits the power of two inside-cylinder compound engines. It follows, therefore, that the same compound locomotive cannot adapt itself so well as an ordinary engine to both light and heavy traffic.

It thus appears that on long level roads, and with such regular loads as are found on the Continent and in North and South America, the compound system might prove more successful than in Great Britain, where inclines are more frequent, traffic is more varied, and fuel cheap. But the system has not hitherto received much attention in the United States or in Canada. Mr. A. B. Underhill has tried a four-cylinder compound locomotive on the Boston and Albany Railroad, and the system has also been tried on a Sydney tramway engine, but the absence of economy in fuel has led to its abandonment. The system has hitherto met with most favour and success in Germany and in England.

Cost.—To save unnecessary expense, Mr. Mallet constructed his early compound locomotives as much like the ordinary locomotives as possible. Mr. von Borries claims that, taking into consideration the additional power gained by using high pressure, a compound goods engine can be made for 2 to 5 per cent. less cost than an ordinary goods engine of equal power;[1] and that a compound

[1] "Compound-Lokomotiven." A. von Borries. Berlin, 1886.

passenger-engine costs 8 to 10 per cent. less than an ordinary passenger-engine of equal power. There can be little doubt, however, that a compound engine, as constructed now, is a little more expensive in first cost than a simple engine of the same maximum power.

In the compound engine, the boiler, steam-pipes, joints, &c., must be made stronger to resist the greater pressure, and extra precautions have to be taken to prevent radiation from the hotter boiler, the high-pressure cylinder, and from the increased surface of steam-pipes where they are exposed. These extra items are to some extent balanced by the smaller size of boiler. Steam-jacketing, if carried out, would further increase the cost; but hitherto little has been done to jacket locomotive-cylinders with steam direct from the boiler, though experiments by Mr. Borodin in Russia prove that considerable fuel economy can be thereby obtained.[1]

The intercepting valve, and copper pipes forming the receiver, and the patterns for two different sizes of cylinders, are the chief items which raise the cost of a two-cylinder compound locomotive; while engines with three or more cylinders have additional parts, which considerably increase their cost. In engines with four cylinders, the tandem system is cheaper than the receiver system. Tandem cylinders are, however, objectionable, because the pistons are difficult to examine; but the receiver system is ready of access, and affords an opportunity of heating the intermediate steam by circulating it among the waste gases of the smoke-box; and, by isolating the high-pressure and low-pressure cylinders, an advantageous difference of temperature is maintained between them.

The cost of constructing a number of two-cylinder compound locomotives does not greatly exceed that of the same number of ordinary engines. The cost of three-cylinder locomotives may exceed that of simple engines by £200 to £250 each, and that of four-cylinder compound locomotives is correspondingly more than this in excess of the cost of simple engines of the same power.

The expense of maintaining the more complicated machines is perhaps even more important than their first cost. In Germany again this is said not to exceed that of ordinary engines,[2] as might be expected from the more equal distribution of strains in the working parts of the compound engine. On the other hand, the use of higher steam-pressure is sure to entail increased attention

[1] Institution of Mechanical Engineers. Proceedings, 1886, p. 297.
[2] "Compound-Lokomotiven." A. von Borries. Berlin, 1886.

to the joints and packing; and it has already been pointed out that compound engines use more oil than ordinary engines. In locomotives with three or more cylinders there is a considerable increase in the number of parts to be repaired, and unless these parts are made to last longer by more substantial design, rendered possible by the more uniform strains in compound engines, their cost of maintenance will be greater than that of ordinary engines.

To roughly estimate the justification for adopting the compound system, it may be interesting to compare the cost of fuel consumption by a compound locomotive with that of a simple engine, running during one year 20,000 miles, and burning 30 lbs. of coal per mile, which figures are slightly below the average for English railways.

Coal burnt in one year by an ordinary locomotive

$$= \frac{20{,}000 \times 30}{2{,}240} = 268 \text{ tons.}$$

Coal saved by compound, 15 per cent. of 268 tons = 40 tons. Thus, in a country where coal costs 10*s.* per ton, £20 per annum would be saved. This represents interest at 5 per cent. on a capital of £400; and if the cost of maintenance be the same in the two engines, and the lifetime of each be, say, twenty to thirty years, it may be concluded that, in a country where coal costs 10*s.* per ton, an extra outlay, not exceeding £400, would be justified in the price paid for the compound engine. Under the above conditions, a two-cylinder compound would be very economical, but the saving of the more expensive three-cylinder compound would be about half swallowed up by the additional interest on its first cost; and it is not likely that the four-cylinder compound would be economical. The cost of converting ordinary engines into compound engines is greater than their difference of cost when both are new. A careful investigation into the cost of converting some small simple locomotives, on one of the Staffordshire tramways, to the compound system, showed that the value of the fuel thereby saved would not pay for the alteration in ten years. It is probably due to the enterprise of English and German locomotive engineers, that the compound system has hitherto been introduced so successfully where coal is cheap. Its success under these conditions is the strongest argument in favour of introducing the system into foreign countries which import coal from abroad, as for instance Northern India, where the price of Welsh coal is £2 14*s.* 6*d.* per ton.

Agricultural Engines.—The chief differences between the appli-

cation of the compound system to locomotives and to agricultural engines is, in agricultural engines:—

1. The use of automatic starting-valves is unnecessary; and

2. Steam-jacketing can be more readily introduced. An agricultural engine can usually be started without much load upon it, and a simple valve, admitting steam to the receiver, is all that is required for this purpose, in addition to the ordinary regulator.

Some years ago Mr. Mallet constructed a locomotive with steam-jackets; but he abandoned the practice because of the increased weight and greater number of steam-tight joints required.

By the use of complete jacketing of both cylinders and steam-passages, in a small experimental condensing engine, using steam at 65 lbs. pressure per square inch from a boiler of ample size, Mr. Druitt Halpin, M. Inst. C.E., in March, 1882, succeeded in developing 1 indicated HP. for every 1·6 lb. of coal burnt per hour. In this trial the amount of water condensed in the jackets amounted to 0·286 lb. per indicated HP. per hour. This shows that a large amount of heat must have been transferred to the steam during expansion, and some loss of pressure thus prevented, which would otherwise have taken place from the natural cooling of the expanding vapour, and from direct condensation of the steam as it entered the cylinder.

Whether the amount of steam saved by jacketing be 100 per cent., as instanced by Mr. Halpin,[1] in an engine under light load; or whether it be nil, as is too often the case with steam-jackets not properly drained; the fact remains that steam, carefully heated during expansion, maintains its pressure better than when expanding in an unprotected cylinder. Agricultural-engine makers have different methods of jacketing cylinders, the common one being to put a liner into the cylinder casting, allowing it to fit at the ends only, and admitting steam at boiler-pressure between this liner and the body-casting. Another way is to cast the liner and jacket in one piece.

Messrs. R. Hornsby and Sons, in 1884, constructed compound portable engines with both cylinders enclosed in a steam dome, placed on the top of the firebox, so that no drain-cocks were necessary, and the cylinders were thus always at the full heat of the high-pressure steam. Messrs. Marshall and Sons,[2] about the same time, commenced making compound portable engines with one neat casting, comprising two cylinders and slide-valve chests, inter-

[1] Institution of Mechanical Engineers. Proceedings, 1883, p. 455.

[2] "The Engineer," vol. lviii. 1884, p. 439.

mediate receiver and stop-valve chamber, on the top of which was a double-spring safety-valve.

Agricultural and portable engines are sometimes worked with condensers, but a sufficient amount of cold water is seldom obtainable, and it is as a non-condensing engine that the modern high pressure compound portable stands in such high estimation. It is probably the most economical engine of its class (end of Table II), consuming even less fuel than most of the finest condensing engines. Numerous experiments show that this class of engine will perform one-third more work than a simple engine with the same amount of fuel and water.

In conclusion, it appears that the compound principle, in its application to locomotives, has been attended by considerable saving of fuel; but that sufficient time has scarcely elapsed to prove the value of some of the other advantages claimed. Increasing the number of cylinders to three or four renders it possible to construct extremely powerful locomotives. Certain minor difficulties connected with the distribution of steam at low-pressure have not yet been entirely overcome in compound locomotives running at high speeds; but although the system may not be suitable for engines working intermittent slow heavy traffic, yet on main-line trains, and in countries where fuel is dear, its advantages are well established.

The Paper is accompanied by eight sheets of illustrations, from which Plates 1, 2, and 3 have been engraved.

APPENDIXES.

TABLE I.—LIST of COMPOUND LOCOMOTIVES.

—	Date when Built.	Name of Railway.	Class of Engine.	Cylinders. Diameter. hp.	Cylinders. Diameter. lp.	Cylinders. Stroke. hp.	Cylinders. Stroke. lp.	Driving-wheel Diameter.	Boiler Pressure per Square Inch.	Weight in working order.	Illustrated.	Number of Engines Built or Building.
				Inches	Inches.	Inches.	Inches.	Ft. Ins	lbs.	tns cwt		
New types of engines.	1852	Eastern Counties	Goods	Both cylinders same size.				..	..	..	..	1
	1852	„ „	Passenger	Both cylinders same size.				..	..	..	..	1
	1875	Bayonne and Biarritz	„	9·45	15·75	17·72	17·72	3 11¼	140	19 10	..	3
	1878	„ „	Goods	11·02	16·54	21·65	21·65	3 11¼	140	24 10	Fig. 16	2
	1878	London & North-Western	Passenger	9	15	20	20	6 0	120	23 5	Fig. 15	1
	1880	Hanoverian State	„	..	..	..	..	..	..	..	Fig. 18	2
	1881	London & North-Western	„	11½	26	24	24	6 6	150	37 10	Altered	1
	1883	Boston & Albany, U.S.	Four-cylinder passenger	..	..	..	..	..	..	..	..	1
	1883	German Tramways (Schichau)	.. ..	..	..	..	..	..	..	..	Fig. 17	2(?)
	1884	London & North-Western	Metropolitan passenger	13	26	24	24	5 9	150	46 17	..	1
	1884	„ „ „	Passenger	14	30	24	24	6 0	180	42 10	Fig. 25	1
	1884	Sind, Punjab & Delhi	Two-cylinder mixed	18	24	22	22	5 0	120	..	..	1
	1884	„ „ „	Four-cylinder mixed	11¾	17	24	24	5 0	120	..	..	1
	1885	Great Eastern	Passenger	18	26	24	24	7 0	160	44 10	Fig. 20	1
	1886	Chemin de Fer du Nord	Four-cylinder passenger	13	18⅛	24	24	6 10¾	156	37 16	Fig. 28	1
	1886	North British (Nesbit)	„ tandem	..	..	..	..	..	160	..	..	1
	1888	Dutch State	Fitted with Mallet's valve	18	18	15·8	31·6	7 0	140	..	..	6(?)
England.	..	North-Eastern	Passenger and tank	18	26	24	24	6 8¾	175	42 9	..	44
	..	„ „	Goods	18	26	24	24	5 1⅜	160	40 7	Fig. 21	32
	..	Great Eastern	Passenger	18	26	24	24	7 0	160	44 10	..	11
	..	„ „	Goods	18	26	24	24	4 10	150	39 8	..	1

TABLE I.—LIST OF COMPOUND LOCOMOTIVES—*continued.*

	Date when Built.	Name of Railway.	Class of Engine.	Cylinders. Diameter. hp.	Cylinders. Diameter. lp.	Cylinders. Stroke. hp.	Cylinders. Stroke. lp.	Driving-wheel Diameter.		Boiler Pressure per Square Inch.	Weight in working order.		Illustrated.	Number of Engines Built or Building.
				Inches	Inches.	Inches	Inches.	Ft.	Ins.	lbs.	tns.	cwt		
England—*cont.*	..	London & North-Western	Three-cylinder passenger	13	26	24	24	6	6	150	37	15	..	30
	..	" " "	" "	14	30	24	24	6	0	180	42	10	Fig. 25	40
	..	" " "	" " side tank	14	26	18	24	4	$8\frac{1}{2}$	160	50	17	Fig. 26	1
	..	" " "	" goods side tank	14	30	24	24	5	$2\frac{1}{2}$	160	43	10	Fig. 27	1
	..	London & South-Western	Two-cylinder passenger	18	26	24	24	7	1	160	45	16	..	1
	..	Great Western	.. ..	..	..	..	..		..	..		..	..	1
	1876–7	Hunter and English	Tram 1 hp, 2 lp. cylinders.	..	..	..	..		..	..		..	..	1
	1886	Birmingham Central Tramways	Condensing tram	9	14	14	14	2	7	180	About 13	0	..	1
	1886	Manchester B. R & O. Steam Tramway	Tram-engine	9	14	14	14	2	7	180	13	0	Fig. 24	1
	1887	Shown at Newcastle Exhibition, 1887	Tram-engine, to work either simple or compound	8	14	12	12	2	4	160	10	0	..	1
Germany.	..	Hanoverian State and Prussian State	Passenger	$17\frac{3}{8}$	$24\frac{1}{4}$	$24\frac{3}{4}$	$24\frac{3}{4}$	6	$1\frac{1}{4}$	176	38	7	..	70
	..		Goods	$18\frac{1}{8}$	$25\frac{5}{8}$	$24\frac{3}{4}$	$24\frac{3}{4}$	4	$4\frac{1}{8}$	176	37	15	..	59
	..	Alsace & Lorraine	Passenger tank	$14\frac{1}{2}$	$21\frac{5}{8}$	$19\frac{3}{4}$	$19\frac{3}{4}$	4	11	176	34	10	..	1
	..	Saxony	"	$17\frac{1}{4}$	$24\frac{3}{4}$	$21\frac{5}{8}$	$21\frac{5}{8}$	6	$1\frac{3}{4}$	176	42	6	..	15
	..	"	Goods	18	$25\frac{1}{2}$	24	24	4	$6\frac{3}{4}$	176	40	16	..	10
	..	Wurtemburg	Passenger	$16\frac{1}{2}$	$23\frac{3}{8}$	22	22	5	5	176	36	8	..	5
	..	Engines with Lindner's Starting-valve	" and goods	..	..	..	..		..	..		..	..	17
America.	..	Western of Buenos Ayres	Three-cylinder passenger	12	26	24	24	5	11	175	39	7	..	2
	..	Central Entre Riano	Goods	16	23	24	24	3	9	175	37	0	Fig. 22	1
	..	Western of Buenos Ayres	Passenger	$16\frac{1}{2}$	24	24	24	5	11	175	38	15	..	2
	..	Buenos Ayres & Rosario	"	16	$23\frac{1}{4}$	24	24	5	$7\frac{1}{2}$	160	35	14	Fig. 23	7

America—*continued.*	..	São Paulo Railway, Brazil	Three-cylinder passenger	12	24	24	24	5	6½	150	..		..	2
	..	North-West Argentine	Mixed	16	23	22	22	4	0	170	32	10	..	6
	..	Argentine Central Northern	Passenger	15	21½	22	22	4	6	175	29	10	..	11
	..	„ „ „	Goods	16	23	24	24	3	6	175	33	0	..	27
	..	Santa Fé & Cordoba Great Southern	Passenger	16	23	24	24	5	6	170	38	2	..	4
	..	„ „ „ „	Goods	17½	25	25	25	4	6	170	46	15	..	6
	..	Central Uruguay	„	17½	25	24	24	4	6	175	36	10	..	1
	..	Central Uruguay, Northern Extension	Goods	17½	25	24	24	4	6	175	36	10	..	3
	..	Central Argentine	5 passenger and 5 goods	18	26	24	24	4 / 5	6 / 1½	165	43 / 44	14 / 0	..	10
	..	Argentine Great Western	Goods	17½	25	24	24	4	6	175	38	0	..	8
	..	Anglo-Chilian Nitrate & Railway Co.	„	17	24	21	24	3	2	170	51	0	..	9
	..	Pennsylvania Railroad	Three-cylinder passenger	14	30	24	24	6	0	180	42	10	Fig 25	1
	..	Antofagasta Railway	Three cylinders	10	20	20	18	3	0	170	35	0	..	2
India.	..	Oudh & Rohilkund	Three-cylinder mixed	12	24	24	24	6	0	120	37	12	..	10
	..	Bengal & Nagpur	Two-cylinder mixed	18	26	26	26	4	4	160	46	14	Fig. 19	4
	..	Nizam's State	„ „	18	26	26	26	4	3	160	44	17	..	2
Europe.	1881–5	Russian South-Western	Goods (Mallet)	16·54	23·62	..	..		..	130	..		..	1
	..	Grazi & Tsaritsin, S. Russia	Goods (6-wheel compound)	..	..	..	..		..	..	..		..	7
	1877	Haironville	Mallet's system	8·66	13·58	15.75	15·75	2	5½	140	15	10	..	5
	1878	Paris & Orleans	„ „	16·54	21·67	25·59	25·59	6	6¾	120	37	17	..	1(?)
	1879	Northern of Spain	„ „	17·33	23·62	23·62	23·62	4	3¼	100	31	15	..	1(?)
	1888	Portuguese Government	Passenger	18½	27	26	26	6	0½	175	..		..	4
	..	Western Railway of France	Three-cylinder passenger	13	26	24	24	6	6	150	37	15	..	1
	..	Austrian State Railway	„ „	13	26	24	24	6	6	150	37	15	..	1
	..	Italian Southern	Goods	..	..	..	..		..	..	..		..	2
	..	Moscow Warsaw	„	..	..	..	..		..	..	..		..	1
	..	Northern of France	Four-cylinder tandem (8-wheeled compound)	15	26	25·6	25·6	4	3½	140	52	0	..	1

TABLE I.—LIST OF COMPOUND LOCOMOTIVES—*continued*. (ADDITIONS by MR. MALLET.)

1	Date when Built.	Name of Railway.	Class of Engine.	Cylinders. Diameter. hp.	Cylinders. Diameter. lp.	Cylinders. Stroke. hp.	Cylinders. Stroke. lp.	Driving-wheel Diameter.	Boiler Pressure per Square Inch.	Weight in working order.	Illustrated.	Number of Engines Built or Building.
				Inches	Inches	Inches	Inches	Ft. Ins.	lbs.	tns. cwt		
Mallet's 2 cylinders.	1877	Contractors	Metre-gauge (4-wheel coupled)	$5\frac{7}{8}$	$9\frac{7}{8}$	$12\frac{1}{4}$	$12\frac{3}{4}$	2 $3\frac{1}{2}$	170	7 0	..	2
	1879	Austrian Northern	Passenger (4-wheel coupled)	$12\frac{1}{8}$	$20\frac{3}{4}$	$22\frac{7}{8}$	..	5 $2\frac{1}{2}$	130	32 0	..	1
	1883 to 1888	Athens-Laurium, Greece	Metre-gauge (6-wheel coupled)	$12\frac{1}{2}$	$18\frac{7}{8}$	$18\frac{1}{8}$		2 $9\frac{1}{2}$	140	28 0	..	1
		Russian South Western	Passenger (4-wheel coupled)	$16\frac{1}{4}$	23·6	23·6		5 7	130	33 0	..	12 to 15
		" " "	" (6 " ")	15·2	21·7	24		4 4	140	35 0	..	
		" " "	Goods (8-wheel coupled)	$19\frac{3}{4}$	28	$25\frac{3}{8}$		4 $3\frac{1}{2}$	140	48 0	..	
		Western of Switzerland	" (6 " ")	$17\frac{3}{4}$	$25\frac{5}{8}$	$25\frac{3}{8}$		4 4	140	36 0	..	1
	1888	French State	" (6 " ")	$16\frac{1}{2}$	23·6	23·6		4 11	130	33 0	..	1
	1889	Staatsbahn, Austria	" (6 " ")	$16\frac{1}{2}$	23·6	$24\frac{7}{8}$		4 2	140	35 0	..	2
	1889	" "	" (8 " ")	$18\frac{1}{2}$	$26\frac{1}{8}$	$24\frac{7}{8}$		3 10	140	47 0	..	2
Mallet's 4 cylinders.	1887	Decauville portable railway	8 wheels, swivelling truck	$6\frac{3}{4}$	10	$10\frac{1}{4}$		1 $11\frac{1}{2}$	170	11 10	..	12 to 15
	1889	Ditto, 1 foot $11\frac{1}{2}$-inch gauge	" "	7·4	11	$10\frac{1}{4}$		1 $11\frac{1}{2}$	170	12 0	..	
	1888	French Departmental lines	" "	10	15	$18\frac{1}{8}$		2 $9\frac{1}{2}$	170	24 0	..	7
	1889	Spain and colonies, metre-gauge	" "	8·9	13·4	13·7		2 $7\frac{1}{2}$	170	20 10	..	6
	1885	Danish State railway	Old engine rebuilt	16	23	22		4 6	..	..	..	1 (?)
	1881	Struwe and Kolomna, Russia	Three cylinders—2 h p, 1 l p (6-wheel coupled)	..	..	..	..	.	..	..	..	1
	1887	Northern of France	Goods, three cylinders—2 h p 1 l p.	..	..	..	..	..	..	..	..	1
	1889	Paris, Lyons, and Mediterranean	Passenger (4-wheel coupled) four cylinders	..	..	..	..	..	210	..	..	2
	1889	" " "	Goods, four cylinders (8-wheel coupled)	..	..	..	..	..	210	..	..	4
	1889	Jura-Berne-Lucerne	Passenger, two cylinders	$17\frac{1}{4}$	$25\frac{3}{8}$	$25\frac{3}{8}$	$25\frac{3}{8}$	5 0	160	45 0	..	3
				Total number of compound locomotives about								569

TABLE II.—FUEL-CONSUMPTION in COMPOUND CONDENSING MARINE and other ENGINES.

Date.	Class of Steamboat.	Expansion.	Coal Consumed per I.HP. per hour.	Remarks.
About 1867	Pacific Steam Navigation Co.	Double	2¼	Using steam at 40 lbs. per square inch.
1872 . .	Nineteen steamers on long sea voyages . .	"	2·11	On ordinary duty.
1872 . .	Steamers on long sea voyages	"	1·30	Working at ⅓ maximum power.
1872–87 .	White Star line mail steamer	"	less than 2	See Paper by J. J. Campbell.
1887 . .	Mail steamers		2–2¼	Liverpool Engineering Society, 1887.
	Ocean steamer	"	1·66	
1887 . .	Cargo steamer	"	1·50	Ordinary speed worked below maximum power.
1887 . .	" "	Triple	1·25	
1887 . .	Steam yacht "Myrtle"	Quadruple	1·20	Best Welsh Penrikyber coal.
		Locomotives.		
About 1884	Philadelphia and Reading Rd. (Mr. Wootton)	Single	3·55	Working express passenger trains for three months.
1879 . .	Bayonne and Biarritz Ry.	"	4·9–5·5	Working at maximum power, *Engineering*, vol. xxxi. p. 95.
1884 . .	London, Brighton and South Coast Ry. . .	"	2·04	A carefully prepared run, with feed-water heater.
1879 . .	Bayonne and Biarritz Ry.	Double	3·3–3·52	Working at maximum power.
Aug. and Sept., 1879	Bayonne and Biarritz Ry. (Mr. Mallet) . .	"	2·96	Train of 58 tons.
Oct. 1883 .	6 ft. 6 ins. passenger engine, L. & N. W. Ry.	"	2·87	Average of a 300-mile run with thirteen carriages.
1888 . .	6 feet passenger engine, L. & N. W. Ry. . .	"	2·3 & 2·15	Load, including engine = 320 tons at speeds of 50 and 27 miles per hour respectively.
1888 . .	Three-cylinder semi-portable engine . . .	Triple	1·45	Made by Marshall and Co., Keighley.

STEAM-CONSUMPTION in SIMPLE, COMPOUND, and COMPOUND CONDENSING ENGINES.

—	Steam Consumed per I.HP. per hour.	—
	Lbs.	
Ordinary simple engine.	26·4	Experiments made by Mr. Marie of the Paris and Lyons Railway.
Compound engine without condenser .	23·1	
Compound condensing engine . . .	18·7	

TABLE III.—CYLINDER-VOLUME RATIO.

Designer.	Class of Engine.	Railway.	Ratio between vol. of lp. cyl. / vol. of hp. cyl.
Mallet . .	Converted from simple engine .	Paris and Orleans	1·71
Sandiford .	" " " " .	Scinde, Punjaub, and Delhi . .	1·78
Mallet . .	Converted from simple engine .	Northern Railway of Spain . .	1·86
Samuel, 1852	Goods	Eastern Counties.	2 & 3
von Borries .	Large locomotives with tenders	Recommended .	2 to 2·10
Webb . .	6-foot wheel, two cylinders 12 inches, one 24 inches, diameter	Oude and Rohilcund . . .	2·00
" . .	6 feet 6 inches express, two cylinders 13 inches, one 26 inches diameter	London and North Western Railway	2·00
von Borries .	Passenger, 1885; 16½ inches and 23⅝ inches diameter . . .	German State Railways . .	2·05
Mallet . .	1881, steam-jacketed . . .	Russia	2·04
Worsdell .	Express passenger and goods .	Great Eastern and North Eastern Railways . .	2·09
Sandiford .	Four wheels coupled and four cylinders	Scinde, Punjaub, and Delhi . .	2·10
von Borries .	Tank	Recommended .	2·25
Mallet . .	Six wheels coupled tank . .	At Paris Exhibition, 1878; Bayonne and Biarritz Railway .	2·25
" . .	1880	Hanoverian Railway	2·25
Webb . .	6 feet express, two cylinders 14 inches diameter, one 30 inches diameter	London and North Western Railway	2·30
" . .	Suburban tank; two cylinders 14 inches by 18 inches, one 26 inches by 24 inches . . .	London and North Western Railway	2·30
" . .	"Experiment" 6 feet 6 inches express; two cylinders 11½ inches, one 26 inches . . .	London and North Western Railway	2·56
Schichau. .	1883, 10⅝ inches and 17 inches diameter	Suburban Railways, Germany	2·56
Webb, Mallet system .	6 feet passenger (converted), 9 inches and 15 inches cylinders	London and North Western Railway	2·77
Mallet . .	Four wheels coupled . . .	Bayonne and Biarritz, three engines	2·78
Marshall . .	Portable engine, 1881 . . .	Cylinders jacketed with hp. steam	3·24
Various . .	Marine engines	.. ..	About 4

TABLE IV.—POINT OF STEAM CUT-OFF IN VON BORRIES' COMPOUND LOCOMOTIVE (CURVED LINK).

——	Forward Gear percentage of Stroke.	Back Gear percentage of Stroke.
hp. cylinder .	75, 50, 40, 30, 20	78 maximum.
lp. " .	78, 58, 49, 40, 30	75 "

TABLE V.—POINT OF STEAM CUT-OFF IN VON BORRIES' COMPOUND LOCOMOTIVE (STRAIGHT LINK)

——	Forward Gear percentage of Stroke.	Back Gear percentage of Stroke.
hp. cylinder .	75, 50, 40, 30, 20	75 maximum.
lp. " .	75, 57, 48, 40, 30	" "

TABLE VI.—RECEIVER-CAPACITY.

Class of Locomotive.	Railway.	Capacity of Receiver ÷ Capacity of Small Cylinder.
Two-cylinder . .	Northern Railway of Spain	1·69
" " . .	South America	1·11
" " . .	Paris and Orleans, 1877.	1·33
" " . .	Buenos Ayres and Rosario, 1887. Cylinders 16 inches and 23½ inches .	0·97
" " . .	Worsdell, Great Eastern Railway express, 1885. Cylinders, 18 inches and 26 inches	1·03
Three-cylinder .	Webb, London and North Western Railway express. Cylinders, 14 inches and 30 inches	1·58
Four-cylinder .	France, one high-pressure and one low-pressure, placed tandem on each side	Very small.
" " . .	India, independent cylinders. Two high-pressure, driving one axle, two low-pressure, driving second axle .	About 1.

TABLE VII.—FUEL-CONSUMPTION

Date.	Where Working.	Coal Burnt per Mile. Compound Engines.	Coal Burnt per Mile. Ordinary Engines.
		Lbs.	Lbs.
1878	Bayonne and Biarritz . .	13·55 Cardiff	..
1878	" " " . .	10·90	..
1878	" " " . .	0·206 per ton-mile, excluding weight of engine	..
1879	" " " . .	..	..
1880	Hanoverian State Railway .	..	..
May 1881	Russia	..	..
1881–1883	"	..	..
1881–1883	"	..	..
1882	Royal Eastern Ry., Germany	15·6	..
1882	" " " .	13·4	..
1883	Crewe and London, L. and N. W. R.	26·6	34·6
1883	South Russia	..	..
1883	Paris-Lyons	..	..
1884	Marshall's portable engine .	7¼	12¾
1881–1885	South Russia, Mr. Borodin.	..	..
June 1884 till May 1885	Metropolitan L. & N. W. R	23·5 including lighting up	31·4
From 21 Feb. till 21 May, 1886	Great Eastern Railway . .	29·4	33·8
1886	Sind, Punjab, and Delhi .	..	..
1886	Northern of France Railway	7·81 kilog. per kilom.	9·7 kilog. per kilom.
1886	Oudh and Rohilkund Railway	37·24	47·27
1887	Newcastle and Edinburgh newspaper train, N. E R	22·5	30 average
1887	Average of one hundred engines on von Borries' principle	..	..
May 1887	Manchester, Bury, Rochdale, and Oldham Tramway	9 lbs. excluding lighting up	13·4
1888	Manchester, Bury, Rochdale, and Oldham . .	8·2—8·7	10·3 to 10·9
May 1887	Buenos Ayres and Rosario .	..	..
1887	" " " " .	22·35	28·20
1887	Western Railway of Buenos Ayres	..	..
1887	Royal Agricultural trials at Newcastle	1·99 lb. per brake HP. per hour	2·68 lbs. per brake-HP. per hour
1888	German State Railways .	..	..
1888	" " "	..	..
1888	York and Newcastle, Scotch Expresses, N. E. R. . .	25	31·4
			Average

of Compound Locomotives.

Saving by Compound Engines.	Remarks.
Per cent.	
..	Including getting up steam and shunting.
..	One engine, average 3,000 miles.
..	65·8 tons average weight of train through year.
35·00	Working at maximum power.
16·50	Compared with new ordinary engines (von Borries')
15–18	Twelve trial trips of 97 miles.
21–23	17,360 miles of trials with express trains.
10–14	Compared with whole series of standard engines.
13·40	Small engines made by Schichau.
18·90	" " " "
23·10	Webb's 6 feet 6 inches three-cylinder passenger-engine (trial trip)
18·00	Mallet's system, a maximum performance.
12·50	Marie's engines.
43·10	This is a portable agricultural engine (not included in the average).
15–25	Experimental goods-engine, five years' working.
25·10	Metropolitan condensing, converted to three-cylinder Webb compound; mileage, 33,000.
13·00	Eleven compound passenger-engines, ran 109,470 miles. Seven ordinary passenger-engines, ran 64,671 "
13·50	One engine with two cylinders; one engine with four cylinders.
19·00	Engine, No. 701, on express passenger work (Revue Générale des Chemins de Fer, May 1887).
21·00	Three of Webb's three-cylinder compound, compared with three non-compounds doing same work.
25·00	Worsdell's 6 feet 8 inches express shown at Newcastle Exhibition.
15–20	On German railways.
32·80	Tram-engine, trials extending over a few days only.
20·30	Fuel is coke, and the consumption is very regular.
10s. per 100 miles	Including coal, oil, &c.
20·75	Both engines working the same regular passenger-trains.
19·00	
25–75	Portable agricultural engines (not included in the average).
13·00	New engines compared.
3·00	Compared with best type of old ordinary goods-engine.
20·30	Both engines running the same regular trains.
18·80	

Discussion.

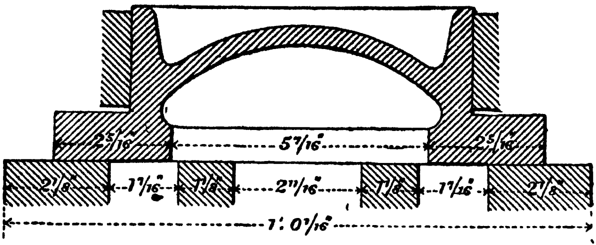
Lapage. Mr. R. Herbert Lapage thought that the advantages mentioned by the Author, namely a more powerful engine, additional power at starting, reduction of wiredrawing, and more even distribution, might fairly be claimed for compound locomotives. During the last four years he had had the opportunity of riding on compound locomotives in Great Britain and on the Continent. Some of the locomotives mentioned in the Paper had been designed or built under his supervision, among others two of Mr. Webb's three-cylinder engines, and some two-cylinder engines on the Worsdell and von Borries system; these engines were now running well and giving satisfaction. With regard to the use of high-pressure steam, no doubt it could be better expanded over more than one cylinder, and a more powerful locomotive could be obtained by compounding. There was also a reduction of wiredrawing, and the more even distribution of the steam naturally took place. That was shown by the cost of repairs when, after about four years' trial with two-cylinder compound locomotives against ordinary ones, it was found to be about 6 per cent. in favour of the compounds. In the case of engines fitted with starting-valves such as shown by Plate 3, Figs. 38 and 39, exhausting into the atmosphere, increased power in starting could be obtained provided the low-pressure engine was strengthened. It was a question, however, whether exhausting into the atmosphere was an advantage or not. Sufficient power was obtained in the ways shown by Figs. 40 and 41; by letting steam into the low-pressure side as described, all the steam was utilized. Drivers were apt to waste steam by exhausting it at high-pressure direct into the atmosphere in order to obtain a momentary advantage, and in that way they used too much steam, since it was not properly expanded. The six-wheeled coupled goods engine, Plate 2, Fig. 22, had been designed by himself, and he was able to try it in 1886 on the Caledonian Railway, through the kindness of the Company; it was fitted with one of the valves (Plate 3, Fig. 41), and he was much struck with the manner in which the engine worked. Forty loaded wagons were taken from Glasgow to Greenock; the engine was only a small one, with 16-inch and 23-inch cylinders, and the train was started and taken in a most satisfactory manner. The engine was also fitted with Mr. von Borries' differential valve-gear, which gave about equal power to each cylinder, and was worked from one shaft as described by

the Author. At p. 21 it was stated that the tank-engines and shunting-engines would have equal cut-offs in both small and large cylinders. Mr. von Borries had the differential cut-off in both forward and backward gear, and it was fitted to the Alsace and Lorraine engine mentioned in Table I. It had a cut-off in forward gear in about the working notch of 40 per cent. high-pressure and 47 low-pressure; full gear 74 per cent. and 78 per cent.; back gear 40 per cent. high-pressure and 44 per cent. low-pressure; full gear 75 per cent. high-pressure and 78 per cent. low-pressure. The engine saved about 18 per cent. of fuel and water. The Author had pointed out that the high-pressure cylinder of the compound engine, when only two cylinders were used, should be somewhat larger than the high-pressure cylinder of an ordinary engine. Mr. Lapage was of the same opinion. Judging from what he had been able to observe and gather, from the engines he had sent abroad, there was no doubt that the high-pressure cylinder should be a little larger; but it all depended on the work to be done and the weight on the driving-wheels. Compound engines would haul heavier trains than ordinary engines with the same boiler-power. With regard to the receiver of two-cylinder engines, he thought it was better to have it about 1½ the capacity of the high-pressure cylinder. As to the steam being throttled in the way described, if a relief-valve were placed on the receiver, loaded to about the working-pressure in the receiver, to let it out, he thought it would be rather an advantage for re-starting. Speaking of the disadvantages of compounding, the Author had pointed out that compound engines had required more oil than ordinary engines. The result referred to might perhaps be ascribed to the engine being new. In specifying a compound locomotive, he put only one lubricator on the high-pressure side, and as the steam went over to the low-pressure side it naturally took up the oil, provided there was no exhaust from the high-pressure cylinder to the atmosphere; moreover, the low-pressure cylinder was somewhat damp and did not need much oil. The machinery should not require more oil, as there was less strain on a compound engine. High-pressure steam was stated to be a drawback; this was not essential, for by arranging the cylinders to the required capacity good results were obtained; but as high-pressure steam could be utilized better in a compound than in an ordinary engine, it was used when practicable. In a two-cylinder compound engine, when the high and the low pressure were arranged to start with about equal power, the moving parts of each engine were of the same dimensions, except as regarded the low-pressure piston and slide-valve, Mr. Lapage.

Lapage. WORSDELL and VON BORRIES' SYSTEM; COMPOUND ENGINE. SANTA FÉ and CORDOBA GREAT SOUTHERN RAILWAY GOODS ENGINE.

High-pressure Cylinder $17\frac{1}{2}$ inches in diameter by 25 inches stroke.

FIG. 1.



GOODS ENGINE. HIGH-PRESSURE CYLINDER.

Angle of F eccentric, $63\frac{1}{4}°$, B 62°.
Clearance in link, top $\frac{15}{16}$ inch, bottom $\frac{5}{16}$ inch.
Slip of die, top $\frac{15}{16}$ inch, bottom $\frac{3}{4}$ inch.
Stroke in mid-gear, $2\frac{5}{8}$ inches.
Length of lifting link, 1 foot $2\frac{3}{16}$ inches.

Lap of valve, $1\frac{1}{8}$ inch.
Inside clearance, $\frac{1}{4}$ inch.
Length of ports, 1 foot 2 inches.
Throw of eccentric, $4\frac{3}{4}$ inches.

Forward Gear.

Notches.	Travel of Valve.	Lead.		Opening.		Supp.		Release.	
		B.	F.	B.	F.	B.	F.	B.	F.
Full.	Inches.	Inches.	Inches.	Inches.	Inches.	Per cent.	Per cent.	Per cent.	Per cent.
6	$4\frac{7}{16}$	$\frac{1}{64}$	$\frac{1}{32}f$	$1\frac{3}{32}$	$1\frac{3}{32}$	76	$74\frac{3}{4}$	90	$89\frac{1}{2}$
5	$4\frac{3}{32}$	$\frac{1}{32}b$	$\frac{1}{16}f$	$\frac{7}{8}\ \frac{1}{32}$	$\frac{15}{16}$	$70\frac{1}{4}$	$68\frac{1}{4}$	87	$86\frac{1}{4}$
4	$3\frac{5}{8}\ \frac{1}{32}$	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{11}{16}$	$\frac{11}{16}\ \frac{1}{32}$	$62\frac{3}{4}$	60	$83\frac{1}{4}$	$82\frac{1}{4}$
3	$3\frac{5}{16}$	$\frac{3}{32}$	$\frac{5}{32}f$	$\frac{1}{2}b$	$\frac{9}{16}$	$53\frac{1}{4}$	$49\frac{3}{4}$	$78\frac{1}{2}$	$76\frac{1}{2}$
2	$3\frac{1}{32}$	$\frac{1}{8}b$	$\frac{3}{16}$	$\frac{11}{32}$	$\frac{7}{16}$	$41\frac{1}{2}$	$38\frac{1}{2}$	$72\frac{1}{2}$	$69\frac{1}{4}$
1	$2\frac{13}{16}$	$\frac{1}{8}f$	$\frac{3}{16}f$	$\frac{1}{4}b$	$\frac{5}{16}f$	$26\frac{1}{4}$	26	64	$60\frac{1}{4}$

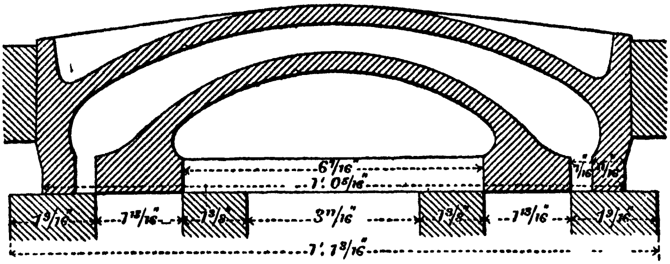
Backward Gear.

6	$4\frac{3}{8}\ \frac{1}{32}$	..	$\frac{1}{16}f$	$1\frac{1}{8}b$	$1\frac{1}{32}$	76	$75\frac{1}{2}$	$88\frac{3}{4}$	$90\frac{1}{2}$
5	$4\frac{3}{32}$	$\frac{1}{32}$	$\frac{1}{8}b$	1	$\frac{13}{16}\ \frac{1}{32}$	$71\frac{1}{4}$	$70\frac{1}{4}$	87	$88\frac{1}{4}$
4	$3\frac{3}{4}\ \frac{1}{32}$	$\frac{1}{16}f$	$\frac{5}{32}$	$\frac{13}{16}$	$\frac{11}{16}\ \frac{1}{32}$	$65\frac{1}{2}$	64	$84\frac{1}{2}$	$85\frac{1}{4}$
3	$3\frac{1}{2}$	$\frac{3}{32}$	$\frac{3}{16}b$	$\frac{5}{8}\ \frac{1}{32}$	$\frac{9}{16}\ \frac{1}{32}$	$58\frac{1}{2}$	$55\frac{1}{2}$	81	$81\frac{1}{2}$
2	$3\frac{3}{16}\ \frac{1}{32}$	$\frac{1}{8}b$	$\frac{7}{32}b$	$\frac{1}{2}$	$\frac{7}{16}\ \frac{1}{32}$	$49\frac{1}{2}$	44	$75\frac{1}{2}$	$75\frac{1}{4}$
1	3	$\frac{1}{8}f$	$\frac{7}{32}b$	$\frac{3}{8}$	$\frac{3}{8}b$	$39\frac{1}{2}$	33	70	69

Mr. Lapage.

Low-pressure Cylinder 25 inches in diameter by 25 inches stroke.

FIG. 2.



GOODS ENGINE. LOW-PRESSURE CYLINDER.

Angle of F eccentric, $63\frac{1}{4}$°, B 62°.
Clearance in link, top $\frac{1}{16}$ inch, bottom $\frac{13}{16}$ inch.
Slip of die, top $\frac{15}{16}$ inch, bottom $\frac{11}{16}$ inch.
Stroke in mid-gear, $2\frac{5}{8}$ inches.

Length of lifting link, 1 foot $2\frac{1}{8}$ inches.
Lap of valves, $1\frac{1}{8}$ inch.
Length of ports, 1 foot $7\frac{1}{4}$ inches.
Throw of eccentric, $4\frac{3}{4}$ inches.

Forward Gear.

Notches.	Travel of Valve.	Lead.		Opening.		Supp.		Release.	
		B.	F.	B.	F.	B.	F.	B.	F.
Full.	Inches.	Inches.	Inches.	Inches.	Inches.	Per cent.	Per cent.	Per cent.	Per cent.
6	$4\frac{11}{16}$	$\frac{3}{32}b$	..	$1\frac{1}{4}$ $\frac{1}{32}$	$1\frac{1}{4}$ $\frac{1}{32}$	$79\frac{1}{4}$	$79\frac{1}{4}$	$94\frac{1}{4}$	$94\frac{1}{2}$
5	$4\frac{1}{4}$	$\frac{1}{32}$	$\frac{1}{16}$	$1\frac{3}{16}$	$1\frac{3}{16}$	75	74	92	92
4	$3\frac{13}{16}$	$\frac{1}{64}$	$\frac{3}{32}f$	$1\frac{1}{8}$	$1\frac{1}{8}$	$69\frac{1}{2}$	$67\frac{1}{4}$	$90\frac{1}{4}$	90
3	$3\frac{7}{16}$	$\frac{1}{16}b$	$\frac{1}{8}f$	$1\frac{1}{16}$	$1\frac{1}{8}$	$61\frac{1}{2}$	$59\frac{3}{4}$	$87\frac{1}{4}$	$86\frac{1}{2}$
2	$3\frac{1}{8}$	$\frac{3}{32}b$	$\frac{3}{16}b$	$\frac{7}{8}$ $\frac{1}{32}$	1	$51\frac{1}{4}$	$48\frac{1}{4}$	$83\frac{1}{4}$	82
1	$2\frac{7}{8}$	$\frac{1}{8}b$	$\frac{3}{16}f$	$\frac{5}{8}$	$\frac{13}{16}$	$38\frac{1}{4}$	$36\frac{1}{4}$	$77\frac{1}{3}$	$75\frac{1}{4}$

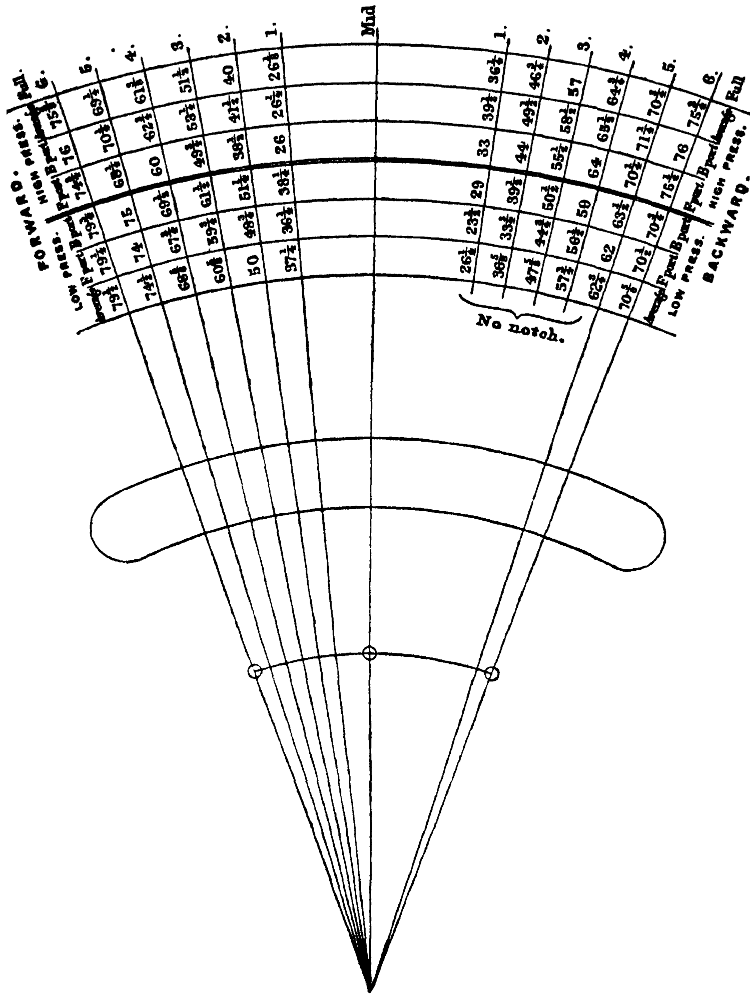
Backward Gear.

6	$4\frac{1}{16}$	$\frac{1}{32}$	$\frac{1}{8}$	$1\frac{1}{8}$	$1\frac{1}{8}$	$70\frac{3}{4}$	$70\frac{1}{2}$	$90\frac{3}{4}$	$91\frac{1}{2}$
5	$3\frac{3}{4}$	$\frac{1}{16}$	$\frac{5}{32}$	$1\frac{1}{8}b$	$1\frac{1}{16}$	$63\frac{1}{2}$	62	$88\frac{1}{2}$	$89\frac{1}{2}$
4	$3\frac{7}{16}$	$\frac{3}{32}b$	$\frac{3}{16}$	$1\frac{3}{32}$	$1\frac{1}{32}$	59	$56\frac{1}{2}$	$85\frac{1}{4}$	87
3	$3\frac{1}{4}$	$\frac{1}{8}b$	$\frac{7}{32}b$	$\frac{15}{16}f$	$\frac{7}{8}$ $\frac{1}{32}$	$50\frac{1}{2}$	$44\frac{1}{4}$	82	83
2	$3\frac{1}{8}$	$\frac{1}{8}$	$\frac{7}{32}f$	$\frac{3}{4}$	$\frac{3}{4}$	$39\frac{1}{2}$	$33\frac{1}{4}$	$76\frac{1}{2}$	$76\frac{3}{4}$
1	$2\frac{15}{16}$	$\frac{1}{8}f$	$\frac{1}{4}b$	$\frac{9}{16}$	$\frac{5}{8}$	29	$23\frac{1}{2}$	$70\frac{1}{2}$	$70\frac{1}{4}$

Lapage.

Cut-off High-pressure and Low-pressure Cylinders for each notch.
Boiler-pressure 170 *lbs. per square inch.*

FIG. 3.



DIFFERENTIAL VALVE-GEAR, REVERSING HANDLE.

so that little or no difference was required for balancing. The cost of compound engines might perhaps be slightly greater; but compounds with the same boiler-power hauled heavier trains than

ordinary engines; and taking into consideration the amount saved in the tender, he believed the cost of the two together would come out about the same. No doubt, as the Author had stated, there was a considerable saving in fuel and water; if such were not the case, so many engines would not have been ordered, the number under the Worsdell and von Borries system having been from three hundred and fifty to four hundred. On the accompanying Tables, pp. 52, 53, was shown Mr. von Borries' steam-distribution as described in the Paper, which Mr. Lapage was applying to some compound locomotives for the Santa Fé and Cordoba Railway, with steam-chests above the cylinders on the American plan. The differential valve-gear on these engines was arranged for running chiefly in forward gear; and in backward gear the two extreme notches were the only ones cut in the sector.

Mr. F. W. WEBB said he was the first in England to take up the principle of the compound locomotive systematically; but, before proceeding to explain his reasons for adopting it, he might mention that he had seen a paragraph in that morning's papers stating that he was building engines 20 tons heavier with triple boilers, &c.; but that was incorrect, as was a great deal that appeared some time ago, because he had ventured out of the beaten track in the way of locomotive building. In 1872, when he took charge of the locomotive department of the London and North Western Railway, the engines were too light for their work; the boilers were too small, and the weight for adhesion was too light for what they had to do. For the first ten years he endeavoured to provide sufficient power by building engines with larger boilers, to bear a higher pressure, and having stronger frames and gearing. That type of engine did very well till 1880, when the speeds were again increased and the trains were heavier. About that time commenced the now almost universal practice on the London and North Western, and other lines, of running first-class carriages with lavatory compartments and other conveniences, which again told very much against the locomotive. In devising a more powerful engine he was met with many difficulties. With the cylinders beyond a certain diameter the sweeps of the cranks would have been too thin, or he would have had to resort to very small bearings, or to an outside frame, which he did not want to do. Seeing the difficulties experienced by some of his brother engineers with powerful engines sending all their work through the crank-axle, he laid out the three-cylinder compound engine. In so doing he was able to divide the work over two axles, to get bearings 13½ inches long, and to do away with coupling-rods. In that way

Mr. Webb. he could have the driving-wheels in any position, and introduce as large a firebox as he wished. He had no desire to make any change, but something had to be done. It was well known that when the first engines were put upon the road there were some failures, but they were only in little matters of detail,—faults of construction due as much to the errors of the drawing-office as to anything. Those difficulties had all been overcome, and there were now working on the London and North Western line seventy-four compound engines; thirty of the "Experiment" type, with wheels 6 feet 6 inches in diameter, 13-inch outside cylinders, one 26-inch inside cylinder; forty of the "Dreadnought" type, with 14-inch outside cylinders, and one 30-inch inside cylinder. Since the engines had been turned out, they had run 10,396,389 miles up to the end of the financial year (November 30th), being at the rate of 42,255 miles per annum for each. "Experiment," which was the first, had run 309,000 miles. In designing the engine he did away with coupling-rods, and had a single crank-axle of a form not likely to give trouble. Indeed, he had never had to change a single-throw crank; and he would undertake to make one of those cranks out of a straight bar in four and a half minutes; so that he not only got the larger bearings, but had the grain of the material in the proper place. Since 1871–2 the speeds of the main-line trains had increased 18·47 per cent., besides being heavier owing to the carrying of third-class passengers by all trains; and last year, being rather pressed for engine-power on account of extra trains, he double-ganged some of the engines. The "City of Paris," which was turned out on the 21st of May last, had, up to November 30th, run 39,741 miles, equal to 74,485 miles per annum; the "Raven," a similar engine, turned out on the 18th of June, 27,085 miles, equal to 59,284 miles per annum; the "Rowland Hill," turned out on the 24th of June, 1886, 104,757 miles, or equal to 44,369 miles per annum. Those engines were double-ganged, and for a time they ran from London to Crewe and back every day, a distance of 1,896 miles per week. The Author of the Paper had mistaken his reason for putting on the valve shown by Fig. 39. He had introduced that valve only on the large engines that ran over the Carlisle district, and he put it on because when running down the long incline from the top of Shap, the engines were rather sluggish. That was due to the big cylinder pumping against the smaller cylinders; he therefore put on the automatic snifting-valve, and if there was a vacuum the valve opened and let in the air. He might be asked why he did not open the cylinder-cocks. In that case he would have let out the lubricant, and have drawn

in the dust and dirt, and cut the cylinder. He found the valve useful, and it gave no trouble. It had not been necessary for the smaller engines running on the Holyhead lines. The Author had stated that the saving in coal should be about £20 per annum. He took 20,000 miles at 30 lbs. per mile, divided by 2,240. The engines shown, however, had run more than double that distance, and if the average on the London and North Western Railway was taken at 20,000 miles it was much under the mark. It only represented the profitable train-miles. But there was a large percentage, 10,000,000 or 11,000,000 miles every year, in the way of shunting and marshalling, of which no account was given; so that the saving should be taken at about 600 tons per annum. Thus there was a considerable saving of fuel for the very little extra cost of building the engine; and double engines had almost been done away with, the total assistance when required being only 0·65 per cent. of the passenger-mileage. Many of the returns of engines on other lines gave, he believed, the actual coal consumed on a given trial trip. He had not so dealt with the coal, because a certain amount was used for getting up steam, and a certain amount of live coal was put into the firebox, besides that in the tender. Every time these engines got up steam they ran on an average a considerable mileage, and he always charged 1·2 lb. for every mile they ran, for lighting purposes, when only about ½ cwt. was so used, but it was the average of all the engines on an engine-mileage of about 50 miles per day per engine at 1·2 lb. All the coal given to the engines was reduced to train-miles. On a line like the London and North Western, it would make a difference of about 6 lbs. per mile upon the coal charged to an engine, as compared with the amount actually required, to do a certain amount of work in a given time. One of the engines, for example, would be in motion, say, six and three-quarters or seven hours, in going from London to Crewe and back; but it might be standing idle five or six hours at Camden Town, and burning coal all the time. In this way it might be taken that the smaller compound engines had burnt 26 lbs. per mile, and the larger engines, which had run with heavy trains from London to Carlisle, 29 lbs. to 30 lbs. per mile for the actual work done. These engines, which had been in constant use, varied very little in their consumption of coal, including all the charges he had mentioned. He had the consumption of all the seventy-four engines reduced to train-miles. The consumption of the smaller ones was 30·2 lbs. of coal per mile, including the 1·2 lb. for lighting up; and for the large engines between London and Carlisle, 36·6 lbs. per mile. He did not

Mr. Webb.

Webb. know what the engineers of other lines, doing a similar class of work at the same speed, could accomplish; but he should be glad, with the consent of the directors of the respective companies, if they would bring their best compound engines for a trial, and he would suggest that Mr. William Anderson, of Erith, should be the Referee. Each engine might come to Lowgill Junction or Tebay, and he would clear the way himself with twenty carriages or more up to Shap, to see what load could be drawn. If any engine could do better than his own, he would undertake to copy the engine that proved to be the best. The relative saving was a very difficult question, as the work was now much heavier and the assistance almost nil. But in one case a compound and a non-compound engine had been doing exactly the same amount of work for the whole of the time; the compound engine had run with 23·2 lbs. of coal per mile, and the non-compound with 31 lbs. per mile, taken over a period of four years, the compound engine in question having been converted from one of the non-compounds, and the working pressure increased from 130 lbs. to 150 lbs. on the square inch. The working expenses, and the shop expenses, had been considerably reduced, and seeing that the capital account was closed, no one could say he took advantage of capital to get at these results.

r. Park. Mr. J. C. Park said that he had not had any practical experience of compounding; but, as the Locomotive Superintendent of the North London Railway, he regarded the subject with great interest. Although he had not a very wide field for using compound engines, the high price of coal rendered the subject one of importance, and he had, therefore, watched the labours of Mr. Webb and Mr. Worsdell with great attention. Many locomotive engineers had not yet dealt with those important questions. The Author had given a good example in Mr. Stroudley's "Gladstone," which had been brought under the notice of the Institution some time ago, as developing about 530 HP. for a consumption of 24 lbs. of coal per mile, attaining a speed of 43 miles an hour with a train of 335 tons, a result on which he thought Mr. Stroudley was to be congratulated. The London and North Western compound engine, however, developed 1,000 HP., and Mr. Worsdell's engine 800 HP., with a consumption of 26 lbs. of coal per mile, with trains of equal weight and speeds of a similar character. If, therefore, the HP. developed was to be the guide, the compound locomotive held the lead; and, taking into consideration the power developed by the London and North Western engine, he thought the three-cylinder type gave out a much greater power than any other kind of engine that had been

designed. In going over the figures he found that the cylinder capacity could be much extended, as if even 17-inch or 18-inch high-pressure cylinders were employed, and the low-pressure cylinder was proportionately increased, the boiler would not be overtaxed any more than that of an ordinary heavy express engine, yet the power of the three-cylinder engine would be far in excess of the other. By admitting steam at starting into the low-pressure cylinder, the tractive force of the "Dreadnought" class was 34,000 lbs., and when compounding 16,000 lbs.; and this great power was transmitted to four driving-wheels entirely free from coupling-rods, a most desirable feature with express passenger-trains. If the time should come to follow the practice in America of pulling very heavy loads, he thought the Webb type of engine would enable this to be done. Mr. Park.

Mr. W. ADAMS observed that some four or five years ago the Directors of the London and South Western Railway, being anxious to effect an economy in the consumption of coal, instructed him to make enquiries respecting Mr. Webb's compound engine, to ascertain if it would be suitable for working heavy passenger traffic. Mr. Webb kindly expressed his willingness to have his engine tried on the line, and obtained the sanction of his Directors for that purpose. The engine "Compound" was therefore sent to Nine Elms steam shed from the North Western Railway, and, without any previous trial over the line, was attached to the 11 A.M. express train from Waterloo to Exeter, returning to Waterloo on the following day. The distance from Waterloo to Exeter was 171½ miles; time allowed four hours thirteen minutes, including six stops, being an average speed of a little over 40 miles an hour. The line between Salisbury and Exeter had gradients ranging from 1 in 70 to 1 in 100. The number of carriages in the train between Waterloo and Salisbury was twelve, weighing about 150 tons, and between Salisbury and Exeter, nine, weighing about 109 tons. For further experience of the compound engine, another trial was arranged for, and it made a second trip to Exeter on the 12th of May, and back on the day following with the same train. Those trials showed that the compound engine was not quite powerful enough for exceptionally heavy traffic, as it did not as a rule start so readily as the South Western engines. Nevertheless it showed great climbing power in ascending the steep grades. The fuel consumption was slightly greater than that of the South Western engine, but this might be expected with an engine so much overworked. In the four trips made by the compound engine, the balance of time lost and made up had Mr. Adams.

Adams. been only five minutes against it. Taking all those circumstances into account, it was considered a very creditable performance. The compound had a pair of 11½-inch high-pressure cylinders, and one 26-inch low-pressure cylinder, the stroke being in each case 24 inches, and the working-pressure in the boiler 160 lbs. per square inch. The South Western engines which worked that traffic were outside-cylinder bogie engines, with cylinders 18 inches by 24 inches, the working pressure being 160 lbs. per square inch, the wheels coupled 7 feet in diameter. Mr. Webb had since those trials built some much more powerful compounds, which Mr. Adams had no doubt would be quite equal to cope with the heaviest passenger traffic. One of the outside-cylinder express engines of the South Western Railway, of the type described, had been recently altered to Mr. Worsdell's system of compounding. A 26-inch cylinder had been substituted for one of the 18-inch cylinders, and the link-motion had been modified to give more travel to the valves. The valves used for both high and low-pressure cylinders were Allan's double-ported valves, sometimes called "Trick" valves. Experiments were in progress to test that engine against others of its class for power and economy of fuel, but they were not sufficiently complete to enable him to give the results to the meeting. He might say, however, that the engine was at present being worked at a boiler-pressure of 160 lbs. per square inch, which was probably too low to obtain the full advantage of compounding. He believed the boiler-pressure adopted by Mr. Worsdell for compound engines was, like Mr. Webb's standard, 175 lbs. per square inch. It might perhaps be more advantageous to use Joy's valve-motion on that engine, as it appeared to be largely adopted in compound engines. It was also a question whether the cylinders might not with advantage be enlarged, say the high-pressure from 18 to 19 inches, and the low-pressure from 26 to 28 inches in diameter, especially if the experiments were continued with 160 lbs. boiler-pressure. That could easily be done, as the cylinders were outside, and well within the construction gauge.

oudley. Mr. W. Stroudley observed that as the "Gladstone" had been mentioned in the Paper, a few words as to the performances of that class of engine might be of interest. Reference had been made to the results obtained in a trial trip between Brighton and London three or four years ago. He had endeavoured to show the consumption of coal per HP. developed in that class of locomotive, and he had a diagram taken for every mile of the distance, with an accurate account of the weight, the speed, and the gradients. He also took great care to arrive at the exact amount of draught on

the draw-bar of the tender. The work due to the lifting of the load up the gradient was carefully ascertained, and there was, he believed, a total of 525 HP. for a train of 325 tons, the consumption being about 2 lbs. of coal per HP. developed, not including the coal used to raise the steam to 100 lbs. pressure per square inch. The object was to test, relatively to the compound engine employed in steamships, the effect of an ordinary engine on a railway; therefore the amount of fuel required to raise the steam in the engine had nothing to do with the matter. Fourteen of the engines had been running, taking all the heaviest work of the railway, and the average consumption, including the raising of the steam, shunting, and the like, came out at about 27·77 lbs. of coal per engine-mile, and 28·65 lbs. per train-mile. He thought it was hardly fair to take 28 lbs. or 30 lbs. per mile as the average consumption of passenger engines. The average consumption of fuel by passenger engines on the Brighton Railway amounted to 24·75 lbs. per mile, the average of all the engines on the line, goods and passenger, being 28·90 lbs. On the South Western line 26 lbs. had been registered as an average. The only object in making a compound engine would be to reduce the consumption of coal and the working expenses of the engine. The greatest difficulty was to make the boiler large enough. If as large a boiler as possible were constructed in the simple engine, there could be no advantage in using a compound engine unless it would do more work with a given weight of steam. The Author had stated that the compound system offered a considerable advantage in regard to starting from the station. In Mr. Stroudley's opinion, the difficulty of getting away from the station was in the want of adhesion of the wheels. In an engine of the "Gladstone" type the regulator could never be opened fully, because the wheels would not hold. They were 6 feet 6 inches in diameter, with four wheels coupled, 28 tons upon the four wheels, and that was not enough to take a train of 350 or 360 tons up a gradient of 1 in 264 without slipping. Various kinds of sanding apparatus had been tried to get over the difficulty, and they did fairly well. One of the heaviest trains, 360 tons, had to run 30 miles in forty minutes, and 20 miles of that distance, including the first 5 miles from the station, was up a gradient of 1 in 264, 10 miles only being down-hill, so that a very strong effort was required to get the train through. The tests he had made showed that an average tractive force of between 500 and 600 HP. was required. He therefore thought that the Author was wrong in supposing that there was a benefit in that direction by compounding, seeing that the present ordinary engine

Stroudley. was able to turn the wheels so far as they could hold. He thought, with Mr. Adams, that the compound principle was a sound one, but at present he did not see much prospect of its advancing far beyond the ordinary well-constructed type of locomotive. The great success that had been attained at sea by compound engines had led to some false conclusions. The conditions of slow-going engines in steam-ships, with a constant load, were altogether different from those of a locomotive. Condensation in the cylinder, referred to by the Author, must depend to a great extent upon the amount of steam passed through it, and it was only in a large engine working a light load that condensation would be mischievous. As the ordinary locomotive was more nearly adapted to the nature of the work it had to perform than the compound, which could not be well adjusted to the varying degrees of load, the advantage gained by compounding would, to a great extent, be lost by excessive dimensions when working a train down a gradient. But the men who had taken up the question were well able to deal with it, and he had no doubt that everything that could be attained in the compounding of locomotives would in time be arrived at by them. But he thought that they ought first to aim at perfection in the ordinary simple arrangement, and judge from that of any further improvement.

Holden. Mr. JAMES HOLDEN stated that there were on the Great Eastern Railway twelve compound engines, eleven of them being passenger express engines, with 7-foot coupled drivers, and one, a goods engine, six coupled with 4-foot 10-inch wheels. They were all of the Worsdell and von Borries type, with two cylinders, 18 inches and 26 inches in diameter respectively and 24 inches stroke. He was inclined to agree with the Author that the value of the compound principle depended very much upon the pressure in the boiler. The eleven passenger engines were originally worked at 160 lbs. per square inch, and at that pressure there was an economy in working them, over the same ground and with the same loads, of 14 per cent. of fuel, as compared with sister engines of the non-compound type. Six months ago, however, a good deal of difficulty was experienced with the boilers, owing to the stays giving way, and he reduced the pressure, pending the building of new boilers, to 150 lbs. per square inch; and taking the six months' working at the reduced pressure, the relative economy of fuel had been diminished from 14 to 2 per cent. He was now building boilers to work at 175 lbs. per square inch, and he expected to get from them much more economy. He could not agree with the Author in thinking that the compound engine developed its maximum

power in starting. The principal difficulty experienced on the Great Eastern line with the compound engine had been in stopping trains. The difficulty in starting was much less now than in early days, probably owing to improved manipulation; the men had got more used to the engine, and were enabled to handle it better. He thought it was somewhat unfortunate that almost all compound locomotives in England were fitted with the Joy valve-gear. Mr. Joy claimed for his gear very great advantages, and the compound principle appeared to him to be so important as to render it very desirable not to mix it up with any other question. Nearly all the engines tried against the compound, except those on the Great Eastern Railway, were fitted with the link-motion. With regard to the wear and tear of compound as compared with non-compound locomotives, there appeared to be very little difference, with the possible exception of the boilers; but on that point he was not prepared to make any definite statement. He was arranging to get some accurate information with regard to the relative cost of repairs of the Great Eastern Railway Company's compound and non-compound engines, as soon as new boilers were provided. There had been at first considerable wear at the front end of the low-pressure cylinder; but he had carried the low-pressure piston-rods through, and this had been considerably diminished. The engines steamed well, although the diameter of the blast-pipes was 80 per cent. larger than in those of the non-compound sister engines. He did not think a full solution of the compounding problem, as applied to locomotive practice, had been reached, but he was inclined to regard its future favourably.

Mr. T. W. Worsdell said that his object in compounding locomotives was not due to any spirit of rivalry. When he left the London and North Western Railway, where coal was comparatively cheap, about 5*s.* 6*d.* a ton, he found that he had to deal with coal at 12*s.* 6*d.* or 13*s.* 6*d.* per ton, and he thought that if any economy was to be obtained by compounding, it should be on the Great Eastern Railway particularly. Mr. Holden had stated that there were eleven compound passenger engines on that railway; those were constructed by Mr. Worsdell when he was Locomotive Superintendent of the line. They were his first efforts in compounding locomotives, and as he had advanced in experience he had been able to improve upon the points mentioned. Since then Mr. Holden had constructed a compound goods engine on his own design, adopting the two-cylinder arrangement on the Worsdell and von Borries system. Mr. Holden Mr. Worsde

Worsdell. had stated that when the engines on the Great Eastern Railway were in proper working order, up to the time that he had some suspicions about the strength of the boilers, he had effected a saving of 14 per cent. over their sister engines, by which he no doubt meant engines built exactly on the same drawings, with the exception of the difference in one of the cylinders. Another point which Mr. Worsdell had aimed at was not to deviate very largely from the general construction of the existing locomotives. He at that time could not afford to be as bold as Mr. Webb and arrange for more cylinders if wanted; but he had to feel his way; and he thought that the trial of two cylinders would show whether there was anything desirable in the compounding of locomotives, especially as there was an advantage in other engines compounded with double cylinders. Of course he fell, very naturally, into the idea that a locomotive engine could be started as easily as an ordinary mill engine or a compound marine engine; but he found that the circumstances were adverse to starting with a fully loaded train, especially at the foot of a gradient, with the ordinary injection steam-valve into the low-pressure cylinder. The reason was, that the steam, entering the chest of the low-pressure cylinder, immediately travelled round and got into the exhaust side of the high-pressure cylinder, and blocked the piston. In certain positions of the valve, perhaps once in ten times, the engine would fail to start; and he set to work to devise some means by which the difficulty could be obviated. The result was the intercepting valve, a means of closing the exhaust between the high and the low-pressure cylinders, so enabling the full power to be got from the steam that was admitted into the low-pressure cylinder without entering the high-pressure cylinder. The Author was right in stating that the starting was generally more readily effected by that principle than by an ordinary engine, because a higher pressure could be obtained. If the low-pressure cylinder was in a favourable position, a much better starting pressure could be got in the large cylinder than in the small one; it remained the same for the high-pressure cylinder. The only point that he had in his mind was the saving of coal, irrespective of the increase of power. He took 18 inches as the initial diameter for the high-pressure cylinder, and he doubled the area, keeping the same stroke for the low-pressure cylinder, and the experiment proved that with the proper arrangement of valves the proportion was as nearly correct as could be expected for the two cylinders. Of course it varied a little according to the speed and the admission of steam. The consumption of coal per HP. per

hour had been referred to. It had not been customary to speak of Mr. consumption per HP. in locomotive-engines, because it was so difficult to say what was the HP. at all times, and to get the proper average. The number of lbs. of coal saved per mile, which was a rough way of estimating, was the usual basis of comparison; but he had estimated it as nearly as he could from a large number of diagrams, and obtained the average for the express engines, taking the trains from Newcastle to Edinburgh and back. From the actual weight of coal consumed in two weeks, he found that the saving in fuel, by compound as against non-compound engines, was about 20 per cent.; but taking the actual average HP. developed over the series of diagrams, the coal burned per HP. per hour was 1·78 lb. He should not have thought it likely to have been so low, had he not been convinced that, in compounding, such results had been shown under very favourable circumstances, and more particularly that the statement of Mr. Stroudley, who had obtained with non-compound engines running with ordinary trains a result of 2·05 lbs. per HP. per hour, was accurate. He found with the non-compound engine that was running the corresponding trains, the consumption of fuel on the trips was taken for about two weeks, and the amount of coal consumed per HP. was 2·74 lbs. Looking at the matter in that light, from the actual facts and indications, there was a considerable saving. The Author's estimate of the total consumption of coal in locomotives was exceedingly low. Mr. Worsdell had got out the amount on the North-Eastern Railway for 1887, and found that two hundred and fifty-four passenger engines consumed 586 tons per engine, on the average, equal to 31·6 lbs. per mile; five hundred and sixty-eight goods engines consumed 597 tons, or 40·1 lbs. per mile; and one hundred and fifty-six shunting engines consumed 364 tons, or 25·1 lbs. per mile. But there were some engines, as all locomotive superintendents knew, that were not rated; their actual mileage not being known, they were allowed a mileage at so much per hour, the train-miles, of course, being taken as absolute. He had never claimed more than an average of 15 per cent. saving in the compounding of locomotives. Instances had come under his notice in which the saving had been greater, but an average of 15 per cent. was all that could be at present relied upon. That would give, for passenger engines, a saving of 88 tons of coal per annum; and for goods engines 89 tons. Even where coal was comparatively cheap, that was a considerable item; but in foreign countries, where the cost of coal was £3 or £4 per

ton, the saving was of course far greater. He considered the starting-valve an absolute necessity for the two-cylinder form of engine. Mr. Webb got over that difficulty in a very different manner, because by his arrangement he had two separate engines. There were, however, certain positions in which the two smaller high-pressure cylinders would have less effective power for starting than the one larger high-pressure cylinder. The valve was very easily applied; it simply went into the exhaust-pipe between the two cylinders, intercepting between that and the receiver. There was another point about the compound locomotive with which his name was associated. It was out of the power of the driver to use live steam continuously in the low-pressure cylinder; he could only use it for starting, and that through a very small pipe; because directly the first high-pressure exhaust occurred, the intercepting valve was automatically opened, cutting off the live steam from the low-pressure cylinder, the engine working absolutely compound, and the driver could not alter it. Mr. Webb had mentioned the fact of having a snifting-valve, or automatic air-valve for the relief of the cylinder, or the engine generally, when running without steam or going down-hill. Mr. Worsdell found it necessary for his engines also, although the low-pressure cylinders were less than Mr. Webb's, and he could understand that it would be a great relief, especially at high speed down a steep gradient. He had stated that he would not calculate upon more than an average of 15 per cent. saving. During the few weeks' running of the accelerated Scotch Express in August, 1888, however, he ran the trains with the same engines used for the ordinary trains. They went from York to Newcastle, where the engines were changed; then from Newcastle to Edinburgh without a stop, the distance being over 124 miles. The non-compound engines consumed 31·4 lbs. of coal per mile, and the compound engines 25 lbs. per mile, or a saving of 6·4 lbs. per mile, equal to 20·3 per cent. As regarded their efficiency on steep inclines, there was a stiff gradient on a portion of the North Eastern Railway, on which a very heavy coke and mineral traffic was hauled across the country from Darlington to Cockermouth. The trains were made up of sixteen wagons, carrying 10 tons each, the wagons themselves weighing about 6 tons; in addition there was a brake-van. There was an incline averaging 1 in 69 for nearly 10 miles. The ordinary train had been worked with a compound tank engine, six wheels coupled, identical with the engine shown by Fig. 21, with the exception of the coal-bunker and the side tanks, and a radial carrying axle under the trailing end. The cylinders were 18 and

26 inches in diameter. The weight of the train was 340 tons, including the engine. On this gradient of 1 in 69, the speed was 14 miles an hour, reaching sometimes 18 miles an hour. The ordinary tender engines for working the trains had 17-inch cylinders, 26 inches stroke, wheels 4 feet 6 inches in diameter, and steam-pressure 140 lbs. per square inch. So that, for long-continued pull of that kind, there seemed to be no reason why the compound engine, with a train of the usual weight, should not suffice. The engine had to stop occasionally, and there was no difficulty in starting. There were now seventy-six compound engines, passenger and goods, and they had given as great satisfaction, in regard to repairs and general work, as any other engines. He was referring to engines that had been at work nearly three years and had not been in the shops for repairs. He could not speak of the mileage as Mr. Webb had done, because he had no engines that had run so long. With regard to the consumption of the six-wheel coupled type hauling heavy mineral trains and express goods trains between Newcastle and Leeds, the load averaging about forty to forty-five wagons; he had taken ten engines built non-compound and ten compound with 26-inch low-pressure, and 18-inch high-pressure cylinders. These two sets of engines were constructed exactly alike in every particular, doing the same class of work, each set during a period of twelve months; and, taking the consumption of fuel from the fuel sheets without any experimental tests, the compound set was 14½ per cent. more economical than the other. The Author had referred to the want of space in the two-cylinder engines, and to the difficulty of construction as compared with the ordinary engine. There was no difficulty in construction. He did not know what the future might produce, but with two large cylinders, developing nearly 1,000 HP., he thought the present limit was sufficient. That power could only be increased at the risk of many changes. It could be duplicated, but that of course meant more working parts, and it meant heavier engines. If the size were duplicated, the size of the boiler would have to be increased, and the size and the strength of every part. No doubt in the Webb three-cylinder engine it was possible to increase very largely the power of the high-pressure cylinders; but if a single cylinder was retained for the low pressure, he would ask Mr. Webb how much larger he would like to construct the single cylinder with the high speed now attained. But he did not think such enlargement would follow, for he considered the trains hauled at the present time were sufficiently long. The strains and the difficulties, in

Mr. Worsdell. connection with the station arrangements, did not admit of increasing very much the weights and lengths of the trains, owing to the inconveniences that were experienced when a maximum of twenty-five coaches had been reached. The holes in the frame presented no difficulty. The frames were made suitable to the cylinders; holes were not cut in them. Any one who knew how an outside-cylinder engine was constructed would at once see that there was nothing in the way of holes like those in the outside-cylinder engines which had valve-chests put through the frames. The Author had stated that the two-cylinder arrangement pointed to the necessity of larger cylinders and higher steam-pressures. That depended very much upon what was meant by the words. The advocates of compounding believed in higher pressures. Otherwise, what about marine engines with their quadruple expansion? Pressures had gone up considerably according to the amount of extra compounding that had been done, and it was obvious that the higher pressure was an advantage, and not a disadvantage. It meant of course provision for a higher initial pressure of steam admitted into the cylinder. In a diagram taken from a two-cylinder compound engine of the Worsdell and von Borries system, the initial pressure was shown to be above the ordinary working pressure; it was about 160 lbs. When the steam had to be exhausted, the end of the cylinder where this was effected became a receiver for the low-pressure cylinder, and the consequence was, what would be called in ordinary working the back-pressure became useful back-pressure, intended to drive the low-pressure piston, and where that back-pressure came in it was necessary to take it off the high-pressure as representing a strain which would be counter to the high-pressure piston; therefore, the strain on the machinery of the engine when it was compounded was considerably less than the strain upon the non-compound engine doing the same work; because taking 160 lbs. and then subtracting 50 lbs. back-pressure only left 110 lbs., instead of 140 lbs. less 5 lbs. back-pressure, or 130 lbs. in the non-compound. He had not found the trouble with regard to boilers referred to by Mr. Holden, nor had Mr. von Borries. He did not see how it could be experienced if the engines were properly constructed, and the material was of the right quality for the high pressure originally. He believed that the boilers referred to by Mr. Holden were made the same as for the non-compound engines, and that it was not contemplated to work them with more than 10 lbs. pressure per square inch in excess of the ordinary engine. He presumed that when boilers of marine engines of large diameter could carry such high pres-

sures as 180 or 200 lbs. per square inch, there was no reason why a locomotive with a small boiler should not be able to carry 180 lbs. The breaking of the stays of course occurred in ordinary engines as well as in compound engines; but he attributed this not to an excess of pressure, but to some other element. He agreed that all high-speed compound locomotives should have very large steam-passages, and he thought there would be a greater saving if the cylinders were constructed with larger steam-passages. His remarks, with regard to the strains due to the apparent high pressure upon the pistons, had reference to what the Author had already to a certain degree pointed out, the wear of the big end brasses, and the connecting-rod brasses, the knocking of the axle-boxes, and the general straining of the machine when high pressures were used in non-compound engines, because those pressures were worst at the early part of the stroke, and not at the effective turning-point of the cranks. If they were, the strains would be relieved; but as it was they became practically useless. Therefore, increasing the dimensions of the cylinders, raising the steam-pressures, and cutting off at an earlier period of expansion, were detrimental to the machine. He had no doubt that those who were now doing so would after awhile see that they had been in error. As a proof of the readiness with which the compound engine was being taken up in foreign countries, and of the acknowledged saving of fuel in places where it was very dear, he might mention that there were no fewer than three hundred engines on the Worsdell and von Borries' system of two cylinders working abroad. There appeared to be a demand for compounding, or some other means of saving fuel, and that could be well understood when, as he had just heard for the first time, one railway company in South America had to pay as much as £4 per ton to get coal to its locomotive stations. With regard to Mr. Webb's challenging any other system of compound engine to work the same train that his large engine of the "Dreadnought" class could take up the Shap Incline, it was evident that no trial could be comparative unless the dimensions were relative, that was, the calculated dimensions for tractive power by the size of cylinder, pressure of steam, and diameter of the driving-wheels. He had not hitherto found it necessary to make the two-cylinder compound engines on the Worsdell and von Borries system any larger than those now in use; but could easily largely increase them if necessary. Mr. Worsdell.

Mr. Thomas G. Iveson said that compound locomotives had not been introduced on the Midland Railway, but, having been accustomed to marine work, he was familiar with the application of Mr. Iveson.

Mr. Iveson. the principle. It was more or less a question of expansion; the more the expansion the greater the saving, and so far as he could see, whatever object there might be in compounding locomotives would be chiefly for economy. This implied a much larger cylinder capacity; and to obtain equal power with a two-cylinder arrangement it was absolutely necessary to enlarge the high-pressure cylinder if the same boiler-pressure was used. The larger the cylinder capacity the greater would be the saving; so far as that went Mr. Webb's was the best compound locomotive he had seen, and he had enlarged the high-pressure cylinder 25 per cent. over the ordinary 18-inch cylinder, the gross capacity being doubled. The great saving in the marine engine was due to its being worked at a much higher initial pressure; for even in compounds the pressure had increased from 70 to 200 lbs., or nearly 300 per cent.; while, independently of its expansive value, the cost of 200-lb. steam was not three times that of 70-lb. steam; and in a three- or a four-cylinder arrangement a very high expansion-rate was possible with moderate strains on parts, and each cylinder kept near the temperature of the steam used in it. One point mentioned in the Paper, and noticed by the last speaker, had been almost lost sight of. When an engine was working compound it had a much smoother motion than if the same expansion were used in a simple engine; but in the case of locomotives where the speed was great, there was a very important change in the power expended upon the axle by the effect of the momentum of the parts, because during the first half of the stroke, the piston-rod, connecting-rod, and other parts had to be set in motion, and a great deal of power absorbed in that way was passed out at the latter half of the stroke. In a quick-moving high-expansive simple engine this tended to equalize pressure on the crank-pin, and should, he thought, be carefully considered in arranging compound locomotives where the reciprocating parts must be heavier, while the power remained nearly the same, though differently distributed.

Mr. Joy. Mr. David Joy remarked that the specialty in which he was engaged had, for some time past, brought him into contact with all the advances that had been made both in locomotive and in marine practice. The two were now running very closely together, and the analogy between them was considerable. There were, however, certain anomalies, and one specially which needed explanation. In compounding a locomotive of, say 17-inch cylinders, taking the data given by the Author, and referring to the Worsdell and von Borries system for simplicity of figures, the

diameter of one of the existing cylinders was increased from 17 inches to 18 inches, and of the other cylinder to 26 inches; and to get equal power, the pressure was raised 20 lbs. Whereas, in compounding a marine engine, referring back to simple compounding, with an engine of two 40-inch cylinders, called 100 HP. nominal, one cylinder for the high pressure was diminished to only 25 inches diameter, and the other increased to 50 inches. Or in tripling an engine of old type, of say, 63-inch and 101-inch cylinders, both these were reduced by lining, and for the high-pressure a 39-inch cylinder only was added, the pressure being increased from 100 lbs. to 150 lbs.; but so great an increase of power was gained as to give the ship a higher speed by 1 knot an hour. It appeared, therefore, that in compounding a marine engine, something was gained which was not gained by the same process with the locomotive; because in the latter the cylinders had to be so considerably enlarged, as well as the pressure somewhat raised. That anomaly however was, he thought, a very hopeful circumstance in regard to the locomotive. He could not agree that the locomotive was under such different conditions from the marine engine as many engineers urged, and which would prevent its participating with the marine engine very largely in the benefits of compounding. It was said that marine engines ran slowly and quietly, and hence the results obtained. This was not now the case; the speeds were greatly increasing. There were cylinders 80 and 90 inches in diameter running at 150 revolutions per minute: and torpedoes at 380 to 400 revolutions per minute. Instead, therefore, of fearing for the future of the compound locomotive, he thought that when experience had taught the best means of compounding locomotives, even greater progress would be made than had yet been accomplished by Mr. Webb and Mr. Worsdell. The use of the Joy valve-gear on compound engines did not make the least difference, so far as coal consumption was concerned; but it played a very important part in the constructive details of the engines. Mr. Joy.

Mr. EDWARD REYNOLDS thought he might, without impropriety, take part in the discussion, because it had happened to fall within his duty to examine and report upon the first example of a compound locomotive-engine. The Author's history in that matter was a little wrong. It was about the year 1849 that the engine was designed, not by Mr. Samuel, such things being altogether out of his sphere, but by an ingenious workman named Nicholson, who was allowed to have his own way, and the result was seen in many crudities in carrying it out, but, in his opinion, not Mr. Reynolds.

Mr. Reynolds. such as to interfere with its success. It was called a continuous-expansion engine. It was originally an ordinary goods engine made by Stephenson with 15-inch cylinders, 24-inch stroke, wheels 5 feet in diameter, four wheels coupled. The slide-valves were altered so that in one cylinder the steam was cut off early enough to exhaust at half-stroke; it then expanded into the other cylinder, and the stroke was finished with the steam acting on the two. He reported at the time, and he still believed, that economy was impossible with such an arrangement, since the pressure of steam in the boilers was only 70 lbs. to the square inch above the atmosphere; and, as the expansion could not under any circumstances be less than four times the original volume, it followed that at anything less than the maximum loads the engine was over-cylindered. He remembered that Mr. Samuel, who fathered the invention, was indignant because the engine put to compare with it was a new engine of a similar class; he said it was a shame to take the best engine on the line; forgetting that the other was supposed to be an improvement, an advance upon the best. The engines were set to work the light passenger trains on the Hertford branch, and the result was, as might naturally have been expected, not a saving but an extra consumption of fuel of 4 or 5 per cent. That the two engines might have been tried as to how much coal each could burn was possible, and that the 12 lbs. per mile mentioned in the Paper might have been realized was also probable, because the compound engine could not take more than two half-cylinderfuls of steam per revolution; whereas the other, which could take steam for three-quarters of a stroke, would do so four times per revolution. Therefore it was quite possible, as to the mere question of how much coal each engine would burn, that the compound engine burned the least. Then, of course, in that particular engine some of the advantages which might now be realized by a compound engine did not exist. The pressure was not high enough, and the two cylinders were so connected together that the advantage of the true rationale of the compound engine was not realized; because the variation of heat in each cylinder was not much reduced. The next example of a compound engine that he remembered was a tramway engine, made by the Yorkshire Engine Company in 1874, on the Perkins system. He believed it was a triple-expansion engine, but he was not quite certain, because, although Mr. Alfred Sacré was kind enough to invite him to have a run with it, he did not look at the machinery. He thought the Paper would fail in its value unless something more than the mere facts connected with the subject were mentioned. The question was, or

should be, under what circumstances would it be beneficial to use compound engines? The gentlemen who had used and described them had stated certain facts which were beyond question, but there were a great many other tales told about them, such as that in the racing to Edinburgh last year all the best records were made with simple engines. He did not know whether that was true or not; but he found himself in a position to believe both sides. Mr. Urquhart had shown him last summer diagrams from some of his engines, and told him that he had realized 20 per cent. economy. The diagrams showed a full charge of steam in the cylinders, under which circumstances economy was possible. But he had remarked that he supposed that the south of Russia was a mountainous district, and that if this economy was realized it must be a level country. Mr. Urquhart replied that there were 500 miles of railway straight and level, and that the loads were full and the speeds moderate. One of the faults of the compound engine was the very thing which was claimed as a merit, that the steam was carried further in each cylinder. That appeared to him to be inconsistent with very fast running. He remembered in his very early days hearing of improvements made on the Liverpool and Manchester Railway, and of a saving of one-half the coke being effected merely by altering the slide-valves on the passenger engines, so as to increase their travel to 4½ inches, making 1 inch lap on each side. Such a proportion as that would make the steam cut-off at about three-fourths of the stroke, the exhaust being opened one-tenth from the end of the stroke, the length of the arc which regulated the time being between one-seventh and one-eighth of a semi-revolution. It was impossible that cutting off steam at three-quarters of the stroke could of itself effect great economy; but it was easy to understand that opening the exhaust-port in proper time might effect economy, because steam, like everything else, had momentum in it; and the mere fact of trying to start the exhaust out as soon as, or very soon after, the admission of steam ceased, and to reverse the direction of the current was itself a difficulty to be overcome. He did not doubt that in all such cases as would enable such diagrams as those exhibited to be got, with pretty full charges for the second cylinder, there was sufficient economy; but he thought that people had been a little misled by marine practice. The Author had properly called attention to the fact that marine work was uniform. The engineer began by constructing a diagram, and he made an engine to suit it; he knew what he had to do, and that it was always alike. But it was well understood in the marine world that it was easy to go too far in expansion,

Mr. Reynolds. even in compound engines. The Author's idea that expansion of twenty-five times would be accomplished, would, he thought, not be realized. It had been attempted with a great deal of skill by Perkins and those who carried out his plans; but had not led to any practical economy. As a striking example of what experience had shown, his company had lately finished the cranks, shafts, and all the steel parts of what would be the most powerful man-of-war in the world, intended to be 25,000 HP. on trial. There were four sets complete of triple engines, it being purposed to disconnect the forward sets from the others for ordinary cruising, because it would not pay to carry expansion too far. That was not a solitary example. Messrs. Maudslay, Son and Field, for example, and other engineers, had made several sets of engines on a similar principle, and he was informed that in France it had been found necessary to make arrangements to disconnect the third cylinder for cruising, because of the absolute loss of power from carrying expansion too far. He thought other interests were involved, of more consequence than the mere question of the little saving of coal that could be effected, at any rate in England, by any great modification of the locomotive engine; because, owing to the absolute necessity for keeping down weight in warships, he knew of examples in which modern engines of considerable size had been made to be driven at excessive speeds; and, in the case of torpedo-boats, there were examples of engines of 12½ and 21½-inch cylinders with 16 inches stroke, driven at 600 revolutions a minute. He had the authority of Mr. Sennett for saying, that though there was a tolerable vacuum in the condensers, there was none in the cylinders. He might be asked, what had that to do with compound engines? He would reply that in compound engines the charge of steam must be carried for a fair distance along each cylinder, and therefore the exhaust-port was opened later than was suitable for very high speed. The practical result was that the average consumption of torpedo-boat engines was at least 4 lbs. of coal per indicated HP. per hour, whereas he was sure that the average of the best ordinary locomotive-engines in England did not exceed 3 lbs.; and no one would doubt Mr. Stroudley's statement that on a special trial it had been reduced to 2 lbs. He believed that if engines for torpedo-boats were made like a good modern locomotive-engine of the ordinary class, an economy would be the result; and that because of what many people described as the defects of the link-motion, which were really its merits. If linked back, so as to cut off at one-quarter stroke, the exhaust would then be opened at about three-quarters of the stroke, giving about one-

third of a semi-revolution for the time of exhaust; and this, he believed, would be far better than charging the cylinder more fully. The Author had alluded to the defects of wiredrawing. The practical result in link-motions, as ordinarily worked out, was this: that when they were linked back a long way, the lead was large, and the compression considerable. The cylinder was pretty well charged at the beginning of the stroke; then during the cut-off, and when the velocity of the piston was rapidly increasing, the difference, between the diagram got by its running away from the throttled steam and the true expansion diagram, was very small; the amount of expansion realized was greater than the mere cut-off taken at a low speed would represent. Then on that point it was said that the wiredrawing might diminish the power of the engine. He remembered, as long ago as 1844, talking to Sir Frederick Bramwell about some small steam-pipes in the steam omnibuses of Mr. Hancock. Mr. Reynolds thought that there would have been a loss of power; but Sir Frederick Bramwell explained to him that if the steam did not get out of the boiler, no power could be lost. The sole question was, when it had got into the cylinder, how to get it out again properly? In practice, with a moderately early cut-off, no harm could arise from wiredrawing so long as the cylinders could receive all the steam that the boiler could supply. The Author had mentioned that when engines were very much notched back there was trouble from the heating of the connecting-rods. That appeared to him, as a railway man of pretty old standing, to be a new disease, if it existed; but he thought there must be some mistake as to its cause. The compression at the end of the stroke was an absolute necessity for a well-working high-speed engine. When last leaving London he travelled by the Great Northern 2 o'clock train to Sheffield, 162½ miles, doing the distance in three hours and twelve minutes. He thought it might be fairly taken that, the average speed being 53 miles, the running speed was 55 miles per hour. The train was taken from Grantham by one of Mr. Parker's new engines, with cylinders of the now most fashionable size, 18 inches in diameter, 26 inches stroke, with which he did not understand that either of the great advocates of compound engines had compared them. The weight of the moving parts, piston, cross-head, connecting-rod, &c., could not be much less than 7 cwt. It might vary, according to the design, up to 7½ cwt. Taking the weight at 800 lbs., with wheels 6 feet 6 inches in diameter, travelling at 55 miles an hour, he had calculated that the effect of inertia at the end of the stroke would be 16,600 lbs., or 65 Mr. Reynolds.

Mr. Reynolds. lbs. to the inch, to be deducted from the indicator diagram at the commencement of a stroke, and added to it at the end. He believed the average work of a locomotive-engine did not, in England, generally exceed 60 lbs. per square inch throughout the stroke, and that 70 lbs. was unusually hard work. He therefore thought that the balancing force equal to 65 lbs. to the inch on the piston at the two ends of the stroke must fully compensate for the action to which the Author had referred, leaving a fair approximation to equality of pressure on the crank-pin.

Mr. Thornycroft. Mr. J. I. THORNYCROFT said that when he commenced building high-speed engines he took for his model the locomotive-engine. It was not then made compound. His endeavour had always been to find the lightest propelling machinery, and triple-compound engines were now being adopted with this object by his firm. The compound engine was lighter than the simple engine when the boiler was included in the weight, and the triple arrangement had an advantage over both simple and compound when the weight of coal for a few hours was considered. In the locomotive, condensation could not be used, so the available range for expansion was more limited, and must finish above the pressure of the atmosphere. He was glad the subject had been brought before the Institution, because he thought that more justice would now be done to the compounding of locomotives. The Author was right in saying that the great variation of temperature in the cylinder of a locomotive was an important source of loss. In comparing the different locomotives, the diagrams, showing clearly the position and size of the cylinders, enabled a correct idea of what had been done to be obtained with much facility. He, however, wished to give some figures in which the change of temperature of the steam in the cylinders was examined; for convenience, these were put in tabular form with some other particulars which did not need explanation. He would remark, however, that the volume of the cylinders per indicated HP. was meant to give an idea of their weight only for a given power. The result obtained by Mr. Stroudley, with a simple locomotive, was so exceedingly good that it required some explanation. This might be found, he thought, in the position of the slide-valves under the cylinders, and in this way they were thoroughly drained of water during the exhaust. There could be no doubt that if there was a cloud of spray in a cylinder, it afforded such a large surface for taking up heat when steam was admitted to the cylinder, and giving it off again when it would be lost, that Mr. Stroudley's plan

of ensuring the best possible drainage was much to be admired. He thought that a record of Mr. Stroudley's experiments, showing the pull on the draw-bar during a long journey, if not already published, would be most valuable in connection with indicator diagrams taken at the same time. It was unfortunate Mr. Thornycroft.

COMPOUND LOCOMOTIVES

Date.	Constructor and kind of Engine.	Boiler Pressure per Square Inch.	Range of Temperature in h.-p. Cylinders (approximate).	Range of Temperature in l.-p. Cylinders (approximate).	Indicated HP.	Area of Cylinders per Indicated HP. $=\frac{V \text{ in cubic inches}}{2 \times \text{Indicated HP.}}$	Do. h.-p. Cylinder only.	Volume swept through by Pistons, per Foot of advance.	Indicated Thrust.	Speed, Miles per Hour.	Ratio of Cylinders.
		Lbs.	°	°				Cub. ins.	Lbs.		
1885	Webb, three-cylinder compound Dreadnought .	175	85	55	810 / 382	30·1	9·1	2,585	9,210	33 / 21	2·3
	Worsdell, two-cylinder compound	175 / 150	52	50	764 / 217	24·6 / 85·0	8·0	1,795	5,210 / 814	55 / 10	2·0
	Schichau, two-cylinder compound	162	50	90	164	41·5	11·7	1,227	4,075	15	2·5
1884 / 1885	Stroudley, simple pressure in steam-chest	125 / 130 / 120	128 / 122		269 / 608 / 452	22·3 / 30·1		1,202	10,100 / 5,710 / 2,822	10 / 40 / 60	
1877	Thornycroft and Co., lightning compound . .	120	77	181	400 / 380	14·2	3·8	..	..	..	2·7
1887	Triple compound	207	58 / 70	84	1,338	15·0	1·84	..	..	..	5·0

that the diagrams of the different compound engines had been taken at such different speeds that their comparison was of little value; in Mr. Worsdell's engine the high speed made the loss in the passages, and resistance to exhaust, appear unduly large; and it seemed that Mr. Webb would have done more justice to his engine if the valve-gear had been adjusted to give more expansion in the low-pressure cylinder, so as to equalize the fall of temperature between the high and the low-pressure cylinders. In this engine the absence of coupling-rods was a great advantage; driving one axle and then indirectly driving another could not be so good as driving each separately. He did not find any

Mr. Thornycroft.

indication of the cylinders being too large in Mr. Webb's engine. He wished to direct attention to the fact, mentioned on p. 12, that the French engineer, Mr. Jules Morandière, had made a suggestion for a compound locomotive in 1866, in which he proposed to use one high-pressure cylinder driving one axle and two low-pressure cylinders driving another. It appeared to him that the scheme was a good one, offering many advantages. There was only one cylinder to keep at a very high temperature. The cylinders might be made all the same size; to start a train, steam could be turned directly to the two low-pressure cylinders. No doubt in the triple engines much steam was saved, but in a locomotive, not using a vacuum, the expansion was of course very limited. The ratio of the high- to the low-pressure cylinder in the triple engine was 5 to 1. The first compound engine built by his firm was designed for a fall of temperature which should be equal in each cylinder, and in order to get that, the steam being cut off at about the same point in each cylinder, the ratio was made about 2½, and he thought that something between 2 and 2½ was the best ratio for locomotives.

Sir Frederick Bramwell.

Sir FREDERICK BRAMWELL said that the remarks of Mr. Reynolds recalled to his mind a discussion in the Institution as far back as March, 1856, on a Paper upon High Speed Steam Navigation.[1] On that occasion, Mr. Edward Humphrys was deprecating excessive expansion, and he gave the instance of the "Retribution," stating that the engine of that vessel had four cylinders, and that they were supplied with steam from four boilers. Sets of diagrams were to be found on p. 339. Fig. 1 was a very fair expansive diagram, Fig. 2 a much fuller diagram; and Mr. Humphrys stated that, calculated according to the Figs., 6½ cubic feet of steam were used for each indicated HP. with the expansion diagram, Fig. 1, while 11 cubic feet were used with the non-expansion diagram, Fig. 2. But Mr. Humphrys said that, so far from these calculations being justified by the results, the fact was that when all four boilers and all four engines were used, 5 lbs. of coal were burned per indicated HP. per hour, while with two boilers working the four cylinders expansively, 8 lbs. of coal were burned per indicated HP. per hour; and he argued from that that there might be over-expansion. Sir Frederick Bramwell observed at that time that he protested against the Institution passing, without demur, a proposition which was adverse to the employment of

[1] Minutes of Proceedings Inst. C.E., vol. xvi. p. 339.

steam expansively. It should be remembered that in these days, the engines were single-cylinder engines, and were without steam-jackets. He remembered Mr. Humphrys saying that he was on board with Mr. Dinnen, with the express object of carrying out the experiment, and he had given orders that the engine should be worked with two boilers, and four cylinders. In the middle of the night he was called by the engineer who said that he could not keep the ship moving. No doubt the poor result was owing to too high expansion in engines as then constructed. But he thought that if Mr. Humphrys were now alive, he would be an advocate for high expansion in marine engines. Bearing these facts in mind, he should not be deterred by the fears expressed by Mr. Reynolds from endeavouring to carry out expansion in locomotives. Mr. Reynolds' remarks appeared to him to be so much like a repetition of that which he remembered some years ago in connection with marine engines, that he trusted the Institution would pardon him for calling attention to the subject. Sir Frederick Bramwell.

Mr. P. W. WILLANS observed that there were a few points with reference to the economical performance of steam in cylinders, on which he might say a few words. The Author stated that the primary object of the various attempts to apply the compound principle to locomotive-engines was to expand the steam in the cylinder more than was commonly done at present, and thus to save fuel; and he gathered from the Paper that when compounding with that end in view the cylinder capacity was frequently increased. Mr. Thornycroft had given particulars of cylinder-capacity as the sum of high and low-pressure cylinders, but that seemed not quite satisfactory. The proper measure of cylinder-capacity in a locomotive, or any other engine, was not high and low-pressure cylinders together, but the low-pressure cylinder alone. The high-pressure cylinder was merely a heat trap, a simple way for saving heat, and it was put in front of the other. The size of the high-pressure cylinder should be governed solely by the proper division of temperatures. Compound engines using the lowest pressure, and having the lowest ratio of expansion, would have the largest collective cylinder capacity by a long way; so that collective cylinder capacity was not a satisfactory measure. With regard to the question of converting a simple engine into a compound, if the low-pressure cylinder capacity was made only the same as that of the old cylinders, and at the same time the steam-pressure was increased, say from 100 to 200 lbs., theoretically at any rate, 25 per cent. more power would be got out of the same cylinder capacity. Suppose the case of a simple engine, taking Mr. Willans.

Mr. Willans. steam at 100 lbs. absolute and expanding fourfold, the steam would approximately be expanded to a pressure of 20 lbs. Suppose now steam was used at 200 lbs. pressure in a cylinder of the same size, about the same terminal pressure would be reached after seven expansions, the useful mean pressure being 25 per cent. greater than before. Therefore he saw no reason, as long as only the same power was aimed at, for increasing the size of the low-pressure cylinder as compared with the old cylinder capacity. On Mr. Worsdell's plan the chances were that the starting power would be better, for he made the low-pressure cylinder of the same capacity as the collective capacity of the two single cylinders, and he made the high-pressure cylinder half that size; it was, therefore, certain that the starting power would be as great if only the high-pressure cylinder happened to be in action, and if only the low-pressure cylinder was in action the starting power would be greater. Mr. Webb, on the other hand, supposing him to be aiming at keeping the same low-pressure cylinder capacity as the old single cylinders, would have only half the capacity of each of the old cylinders in each of the high-pressure ones; and, consequently, only half the old starting power if the low-pressure crank happened to be on the centre. He must, therefore, be driven to larger cylinders to get the old starting power; he did not see that it could be for any other reason, for he would get no economic gain from increasing so much the size of the cylinders. The Author had stated: "Some engineers maintain that anything in excess of a fivefold expansion in locomotives must result in disappointment, and that even with this ratio some amount of superheating between high-pressure and low-pressure cylinders would be desirable, if not necessary." "But," he added, "the indicator diagram, Plate 1, Fig. 3, represents an eightfold expansion with a residual pressure of about 8 lbs." The reason that this pressure was got with eightfold expansion was not that it ought to be got theoretically, or that there was any advantage in getting it, but because there had been a great deal of initial condensation, and, consequently, a great deal of re-evaporation. Starting with the steam-pressure shown on the diagram, 8 lbs. ought to be reached after only 6·2 expansions instead of after 8. The Author stated: "In slow-moving engines, with well jacketed cylinders, it is frequently advantageous to use a tenfold expansion for steam at 160 lbs. pressure above the atmosphere, the steam being in these cases exhausted at a pressure of about 2½ lbs." Mr. Willans was sure that it was not, and could not be, advantageous to do this; 2½ lbs. ought to be reached after 7·4 expansions, and if it was not reached at that stage it was

because there was a great deal of steam that ought not to be there. Mr. Willans. "The same steam, after a fivefold expansion, retains 20 lbs. pressure." This was simply 175 lbs. expanded according to Boyle's law, which had no bearing on the question. "But," said the Author, "simple adiabatic expansion cannot be obtained in a locomotive." Such expansion as the Author referred to was not adiabatic expansion. The Author said: "Considering the unsuitability of the link-motion for earlier steam cut-offs than 30 per cent., there appears to be no other alternative in approximating to a theoretical tenfold expansion than by passing the steam through two cylinders in succession, which is known as the compound system." Mr. Willans would like to know whether if the valve-motion could be made ever so perfect, it would do away with compound engines. The object of compounding was simply to reduce the range of temperature in any one cylinder, and that would be done whatever the valve-motion. He quite agreed with the engineers who maintained that anything greatly in excess of a fivefold expansion in a locomotive must result in disappointment. A locomotive was, perhaps, the least likely engine to get any very great gain from compounding. It was an engine in which many of the conditions already told for economy. It had high speed compared with its cylinder capacity, Mr. Webb's engines running over 300 revolutions with comparatively large cylinders; therefore an enormous quantity of steam passed through them, and the percentage of initial condensation must be smaller than usual. On the other hand, there were several points which told against economy when the engine was compounded. The valve-motion had to be constructed to suit the special requirements of locomotives, and not from a purely economical point of view; and there was necessarily a good deal of choking at certain times in the cylinder, which could not be got over. The locomotive-engine was therefore a compromise as far as compounding was concerned; and he thought it was impossible to say what economic gain would result until accurate figures were submitted. Mr. Webb had suggested that locomotive engineers might make competitive trials up the Shap Incline. It appeared to Mr. Willans far more important to have a thoroughly good brake trial or indicator trial, so as to ascertain exactly what water per indicated HP. or per brake HP. was used. He did not know that the figures for coal per train-mile appealed directly to many engineers. Locomotive engineers might do something in stating what the engines used per indicated HP., in coal if they liked, but certainly in water. Coal per train-mile might, and probably did, give the information

Mr. Willans. they themselves required; but the question was: Had they made the best possible compound engine? Mr. Willans thought not, and no one could say for certain until the figures for water per HP. developed were known. It was curious that the first of his engines, which was compounded, was made for a tram-engine. It was made by Hunter and English in 1876–7. One cylinder was high-pressure and the other two were low-pressure; and he believed with Mr. Thornycroft that that arrangement would make by far the best compound locomotive. All three cylinders were the same size, and by an exceedingly simple valve the high-pressure steam was admitted to the two low-pressure cylinders to obtain starting-power. Messrs. John Penn and Son had used those proportions of cylinders for their marine engines. They might not be the best for marine cylinders now, but they were, he thought, the best for locomotives, and would give the full starting-power as before. It was also a practical advantage to have all parts interchangeable. The Author had referred to the question of superheating in the uptake. He should like to know what gain had been proved to result from the passing of exhaust-steam from the high-pressure cylinders through the smoke-box. He should imagine that it would be theoretically the worst possible use to which the heat in the smoke-box could be put. If there was nothing else to do with the heat he might try to superheat the steam between the two cylinders; but if he could heat the feed-water (he believed Mr. Stroudley heated the feed-water by waste gases in the smoke-box), that would be a great deal better economically. He thought it was very doubtful if much heat could be transmitted to the steam in passing through a pipe from one cylinder to the other. The Author had said, "It was difficult to persuade engine-drivers to work steam expansively." If he meant that it was difficult to persuade them to work with tenfold expansion he was not surprised, if their pay in any way depended upon the consumption of coal. He considered the Paper a very valuable one, and he hoped that the full discussion on it would induce locomotive engineers to make exhaustive trials, and publish the results, so that they could be compared with other results, which was not the case at present. He had no doubt that compound locomotives would eventually do much better economically than simple ones; better, he believed, than the figures so far available might lead many to expect; but the important question was: Had locomotive-engines approached in economy to other non-condensing compound engines? In other words, did they use as little water per HP. hour? He was sorry to find how very scanty was the information on this point.

Professor ALEX. B. W. KENNEDY remarked that the statements in the Paper had received more or less of approbation, from all those who were most qualified to speak of them, as presenting, at any rate, a pretty fair view of what had been done. He himself wished for a great deal more information from the locomotive superintendents, to whose ingenuity and practical ability the development of the compound locomotive was due. It would be admitted that the compound locomotive had been brought to its present state with extraordinarily few practical failures and troubles, considering the difficult nature of the change which had to be made. The change from simple to compound in marine engines was not at all as complicated a matter as the similar change in locomotives. The question of altering locomotives from simple to compound would, of course, be looked upon by the manager of a line from two points of view; first, whether he was going to gain something in expenses of repairs and maintenance, and perhaps in power and convenience of working, and secondly, whether the engine was going to be more economical of fuel. On the first of those points a great deal had been said, and he gathered from those who could speak with authority about it that, at any rate, there was at least no considerable difference as against the compound, and that the question of the economy of fuel was therefore entitled to be considered as a very important one. It had been apparently recognised by those best qualified to speak, that if a compound engine saved 20 per cent. in the coal bill, it was at any rate not going to lose nearly that 20 per cent. in the cost of maintenance. That, of course, was not a matter on which he had a right to form an opinion, but it appeared to be admitted. Then going straight to the matter of economy, he would ask his fellow members, if after all that had been stated in the Paper, and after all that had been said during the discussion by those who knew more than any others about the performance of these compound engines, they had become any wiser on the question of economy? He had tried to follow the figures given, but he had not succeeded in arriving at any definite figures on this point. Seeing that the matter was of so much importance, and was in the hands of companies who were so wealthy, and of locomotive superintendents who had such great facilities for carrying out experiments, he felt very sorry that more experiments worthy of the name had not been made. He said that the more confidently because of the remarks of Mr. Worsdell, who plainly stated that the experiments already made were extremely defective, and who had done not a little, in the information he had placed before

Professor Kennedy.

Professor Kennedy.

members, to put matters on a more satisfactory basis. They were not only defective in not giving absolute results in terms which could be understood or compared among themselves, but they were defective in not giving comparative results as between compound and ordinary locomotive-engines. From a commercial point of view the total coal bill of a line, or of certain portions of a line, was an all-important matter. But then, in the first place, civil engineers could not look at the matter entirely from a commercial point of view; and in the second place, he doubted whether, even from a purely commercial point of view, it was not much better to have much more accurate figures than any that had yet been given. The rough-and-ready train-mile method, to which Mr. Willans had alluded, was incomprehensible as a measure of economy. If only from the immense difference between the various figures cited in the Paper and by those gentlemen who had spoken, it was obvious that the consumption per train-mile was a thing which, however valuable it might be to the superintendent in charge of the line, as a rough means of comparing the performance of certain locomotives with that of others on certain particular portions of the line, and running certain particular trains, could hardly be taken seriously as a standard. It appeared to him impossible to make any serious or intrinsically valuable comparison on such a basis. Why should not simple and compound locomotives be tested against each other, just as any other machines were tested? There was no difficulty, as he could state from his own personal knowledge, in measuring, over some considerable distance, the coal consumption and the water consumption of a locomotive, as well as taking cards, and even collecting the chimney-gases, so as to find out the action of the boiler. It could all be done on a locomotive while running. Mr. Stroudley's notes of a complete run were quoted in the Paper, and about these the only serious fault to be found was that the distance between London and Brighton was so short. If Mr. Stroudley would only keep down the pace, and take three or four hours in doing the journey, the average coal consumption might be measured with something like accuracy. But surely it was as necessary here as in many other cases to separate the results of the engine from the results of the boiler. Even if the coal was measured per indicated HP., it was assumed that the boilers were equally efficient in all engines, and that ought not to be assumed in such a matter. It was essential to know the quantity of steam used, not of coal, to find the value of the improved engines. Another matter had been alluded to in connection with the coal consumption. It

had been said, very properly from a certain point of view, that to ascertain the total saving of fuel due to a particular type of locomotive, all the fuel used when the engine was standing, when the steam was being got up, and so on, must be taken. That was true enough; but surely the fuel used at those times went to the boiler, and depended on the boiler, not on the engine, and would be the same whether there were three cylinders or one cylinder. Therefore, although from the point of view of the total coal bill he admitted that what had to be known was the total saving, still if the coal bill showed a reduction of only 10 per cent., while the new engines could be proved to be using 25 per cent. less steam than the old ones, the moral was not that the compounding saved only 10 per cent., but that there was a loss of 15 per cent. from other causes, and that it was time to do something to minimize those causes. By way of a small practical conclusion after all this fault-finding, he wished to give a few figures, which might be of some interest respecting a locomotive trial which Mr. Donkin and he made a short time ago, because such figures were often inaccessible. Among other trials which they had made, they had experimented on a simple locomotive on the Great Eastern line, kindly placed at their disposal by the company, through Mr. Holden, by whom the engine was designed. Their object was really to test the boiler: it was one series of boiler-tests; but they tested the engine simultaneously. They first had the engine jacked up and set to drive the machines in the shop and a brake, so as to get some resistance on it, and worked it as a stationary engine. They had then two runs between Stratford and Lynn, Mr. Holden having the line cleared for the purpose. They took four hours and a half on the journey, so that they were more or less at leisure. The engine was a six-coupled tank goods locomotive, with cylinders 16 inches by 22, and having 859 square feet of heating surface. Running it as a stationary engine they managed to get 120 HP. out of it, with an evaporation of $12\frac{1}{2}$ lbs. of water from and at 212° Fahrenheit per lb. of Nixon's navigation coal, the best that could be got. On a trial of eight hours and a half duration, with steam of 130 lbs. per square inch, the result was 37·9 lbs. of water evaporated per indicated HP., and $3\frac{3}{4}$ lbs. of coal consumed per indicated HP. He need hardly point out the difficulty of getting any large power in running an engine stationary. They then ran the engine to and from Lynn, and the two trials had almost identical results. The mean HP. was about 130; the water evaporated per lb. of coal reduced to standard was 12·5 lbs. on one trial, and 12·3 lbs.

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Professor Kennedy. on the other; the duration was nearly five hours in each case. The water evaporated per indicated HP. was 33·4 lbs. and 31·2 lbs., and there was a consumption on the two trials of a little over 3 lbs. of coal per indicated HP. The train drawn weighed 263 tons on one journey, and 294 tons on the other, including the weight of the locomotive and tender in each case. The general result, of course, was to show that the boiler, at least when worked well within its power, was an extremely economical steam-generator, and that the engines were perhaps more economical than could have been expected under the circumstances. It was not very easy to get the indicated HP. It was natural to take diagrams at equal intervals of time, but obviously that would not do on a locomotive trial, because in the same time the distances traversed might vary so greatly. No doubt the best plan would be to take them, as Mr. Stroudley did, at equal intervals of distance, but that was not always easy. What he was himself able to do was to take them both at known times and at known places. The $\frac{1}{4}$ mile of line where the diagram was taken was noted, and in plotting it out afterwards it could be found that the mean pressure in the cylinders was so much over so many hundred yards. In that way there would be so many foot-lbs. of work done over a particular distance, so many over the next, and so on; and a very good average would be obtained of the indicated HP. To show the difference, he might mention that the indicated HP. on one trial, calculated in this fashion, came to 121, while the arithmetical mean of the cards was 130. Of course the train would travel a much longer distance in a given time when going down hill. He regretted that the Author had given currency to some heresies in quoting stories about coal consumption in marine engines. Of course the Author had not really made himself responsible for them, but still Professor Kennedy was sorry that they had appeared in the Paper. It was stated that the consumption in a yacht was 1·2 lb. per indicated HP., and other figures were cited such as 1·25, 1·5, and 1·3 lb. He was quite certain that those figures were not supported by evidence. It was much to be regretted that so many of those most interested in marine matters should still countenance the repeated publication of incorrect statements, as if they were scientifically ascertained facts.

Mr. Aspinall. Mr. J. A. F. Aspinall said it must be difficult for persons who were not dealing with such figures every day to understand the value of a train-mile in regard to coal-consumption, because the railways differed so much among themselves; the gradients were different, and the loads were different. No doubt the best South Wales coal was used for Mr. Webb's expresses, while Mr.

Johnson and Mr. Stirling had a very different material. In Lancashire the coal was inferior, and in Scotland still worse. Thus an ordinary mind did not perceive the exact value of the amount of work done. Still it was a convenient unit, and he was of opinion that locomotive engineers would continue to use it. With regard to the question of the economy of compound engines, he thought there was a tendency to give a little too much credit to the engine and not enough credit to the boiler. With compound engines higher pressures were introduced, and much economy was due to the pressure, and possibly also to the engine. A few years ago he had to build some passenger engines for the Great Southern and Western Railway of Ireland somewhat more powerful than any he had to build before. They had cylinders 18 inches by 24 inches, and 160-lb. steam-pressure in the boilers, and were substituted for engines which had cylinders 17 inches by 22 inches, and a boiler-pressure of 140 lbs. per square inch. The consequence was that the consumption of fuel per train-mile dropped from 27 lbs. to 23½ lbs., the difference being entirely due to the increase of pressure. No doubt, to get the full benefit of compound engines, higher pressures than had yet been reached would have to be adopted. What had been done with ordinary simple engines was well shown by the passenger engines recently built by Mr. Johnson for the express trains on the Midland Railway, where the consumption of coal was from 20 to 23 lbs. per train-mile. Mr. Webb in his remarks might have induced the belief that the Author was wrong in his estimate of 20,000 miles per engine per annum. Mr. Aspinall thought it was a fair estimate, taking the number of miles run, and dividing them by the number of engines possessed by any railway company. Mr. Webb had obtained special results with his engines by double gangs, and no doubt that was a course which had some elements of economy when the engines could make very long runs; though 48,000 miles could not be taken as the average mileage per engine per annum. But the point was whether the compound engine was an economical machine or not, and it was necessary to take the average results of all the engines in order to ascertain that point. He differed from the Author as to the consumption of fuel per train-mile. He had put the average at 30 lbs. On five of the leading railways running north, the consumption was something like 40 lbs., taking the passengers and goods engines together, and that would make a considerable difference in the estimate of the saving effected by using compound engines. In referring to the question of using the Joy valve-gear, he was not sure whether Mr. Holden meant that

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Aspinall. it was unsuccessful, and he might therefore state some results which had been obtained with it on the Lancashire and Yorkshire Railway. When he first went to that railway, he found a number of engines built by one of the Glasgow makers, which were fitted with the Joy valve-gear, and a number of other engines fitted with the ordinary gear. They had all been built at the same time, and had been working the same trains continuously, doing similar work ever since. The result was that the engines which had the Joy valve-gear had run an average mileage between the shop repairs of 62,344 miles, while the others had run 51,319 miles. He did not mention those figures for the purpose of showing that the Joy valve-gear was better than the ordinary link-motion, because he did not think that it was; but with the former it was possible to get in much larger axle-boxes, and bearing surfaces. He believed that the extra mileage was due to the larger bearing surfaces rather than to the kind of gear, but the gear had the advantage of keeping the engines out of the shops longer. With regard to Mr. Worsdell's system of compounding, it was of course a very great advantage to be able to take any engine, and put in a pair of cylinders, one large and one small, and make it compound at once. By Mr. Webb's system, a much more radical alteration was needed, though there again there was a considerable advantage in getting a much more powerful engine. One of the best examples of Mr. Webb's compound engines was found on the Metropolitan line, where there was greater economy than in any other case, the reason being that the engine was constantly doing very hard work. If economy was to be obtained by compounding, it must be with an engine working hard during the whole of its trip.

Mr. Cowper. Mr. E. A. Cowper agreed, with Professor Kennedy, that more minute information was required on some points referred to in the Paper. Of course the train-mile was the principal point to which locomotive superintendents looked, and for that reason it had always been a standard. Mr. Reynolds had alluded to the question of letting steam out of the cylinder. Although important, Mr. Cowper did not think letting steam out at the proper time was of so much consequence as letting it in. Many years ago, before the Eastern Counties Railway was opened, he had an engine with a good deal of lap outside and inside. He objected to the lap inside, but it was retained by the superintendent. While he was away on a holiday, however, Mr. Cowper took out the lap inside, and then there was almost always much more steam to spare, and the engine went easily. The result had been given, in the Paper, of a comparison between compound locomotives working on the

Bayonne and Biarritz Railway in 1879, and simple locomotives doing similar work; and it was said, "both engines worked at their maximum power," with "a saving" in fuel "of 35 per cent. in favour of the compound locomotive." That was clearly an unfair trial, because the compound engine was obliged to work expansively, and the simple engine would work nearly full steam at its maximum. On p. 8 it was stated that large single-cylindered stationary engines were worked as economically as compound engines. That he entirely denied. He had as early as 1844 made some 35 HP. economical engines, with single cylinders, but not since, as the best economy could not be got from them. In 1853 he introduced the steam-jacketed reservoir for the high-pressure cylinder of a compound engine to exhaust into, and from which the low-pressure cylinder received its supply, the steam being cut off in the low-pressure cylinder, at or before half-stroke, to prevent a second quantity of steam from the high-pressure cylinder entering in the middle of the stroke. That plan, especially designed for improving the working and economy of compound engines, was now so well known as "Cowper's hot-pot" that he need not enter into details. With regard to the great and well-known advantages of steam-jackets, he thought their defence was somewhat laboured at p. 8, and an attempt had been made to give them the go-by, both there and at p. 37, where their cost was spoken of as still further increasing the price of a locomotive. He was glad to be able to state the fact that there was only an extra cost of about 5*s*. per cwt. in casting locomotive cylinders steam-jacketed, compared with unjacketed cylinders, and the former would weigh rather more with the jackets cast on. Steam-jackets would at once do away with the complaint of a variation of temperature through the stroke. He should much like to see an attempt to apply steam-jacketed cylinders to a locomotive; he felt sure good results would be obtained. The jackets could be continued only so far round the cylinders as there was room for them, and the covers could well be steam-jacketed, they being as important as any part, seeing that the steam came in with a rush between the comparatively cool piston and cover, and much of it was condensed at the very first. The passages also were cool in an unjacketed cylinder. He thought it unnecessary to demonstrate what he had proved forty years ago, namely, that cylinders without steam-jackets condensed steam largely, and then re-evaporated the water. A glass tube attached to a cylinder would prove the fact. At p. 11 it was stated, "The compound system has found very wide and successful application in mill engines."

Mr. Cowper.

Mr. Cowper. It might have been added in steam-ships and water-works, and wherever a truly economical engine was wanted. It had been adopted without its being necessary to raise the steam to a high-pressure, since, as far back as 1870, he had worked with 1·3 lb. of coal per HP., with a pressure per square inch of 55 lbs. of steam only. Six or seven Admiralty trials had been made to and from the coast of France, at different speeds, with a consumption of coal of 1·98, 1·70, 1·60, and 1·30 lb. at a 10-knot speed.

McDonnell. Mr. ALEXANDER McDONNELL considered that engineers were all, to a large extent, agreed upon the question of economy in a compound engine as compared with a single engine, as far as the economical working of the steam was concerned. But there was another question, namely, whether it was possible in a locomotive-engine to carry out the compound principle with advantage. The difficulty was that experiments of that kind could not be carried out in a few days. Professor Kennedy was anxious to conduct such experiments, but the wear and tear of an engine could only be experimented upon during a long period of use. There were some points in regard to the economy of the engines where the results were still wanting. What was to be said about the boiler? It was stated that the boiler would not cost any more. He was certain that no locomotive boiler worked at a pressure of 180 lbs. per square inch would last as many years as one worked at a pressure of 140 lbs. It was possible, from the smaller quantity of coal consumed, that the firebox might last a little longer, but the boiler itself would not. Mr. Holden did not state the age of the boilers on the Great Eastern Railway (it could not have been more than eight years); but it had been necessary to renew them, and he found that when the working pressure was reduced, the economy, to a large extent, disappeared. Then it should be remembered that the locomotive was not always doing uniform work, as in the case of marine engines. It was sometimes running up hill, and sometimes down hill; sometimes at high, and sometimes at low speed; sometimes drawing heavy trains, and sometimes light ones. He did not see the necessity for extremely heavy and powerful locomotives for working ordinary traffic. The passenger traffic receipts of the Great Northern Railway had fallen from 41·78*d.* per train-mile in the half year ending June 1877 to 30·03*d.* in that ending June 1887. One-half of the first-class traffic, and more than half of the second-class traffic, had gone into the third-class. That did not look like the public wanting more accommodation and higher speed. It might be said that the Great Northern Company found it necessary to run those trains to secure

traffic which the Midland would otherwise take. In the case of the North Eastern Railway there was a monopoly which could not be taken away, and what were the figures there? Comparing the year 1877 with 1887, the following were the results:

—	1877.		1887.	
	—	Per Train-Mile.	—	Per Train-Mile.
		d.		*d.*
Passenger train-miles	7,765,398	..	10,168,211	..
	£.		£.	
First-class receipts	201,204	6·22	127,483	3·01
Second " "	148,287	4·58	63,403	1·49
Third " "	1,062,964	32 85	1,246,824	29·43
Season tickets	61,677	1·90	82,963	1·95
Total receipts from passengers	£1,474,133	45·5	£1,520,678	35·88

The train-miles had been increased very much out of proportion to the traffic. Were more powerful engines required to do the work? The first-class traffic per train-mile had decreased to one-half, and the second to one-third of what it was in 1877. The receipts from parcels, horses, and dogs were £252,949, or 5·96*d.* per train-mile in 1887, which was better than the first and second-class receipts put together. The passenger receipts in 1887 were £46,545 in excess of the receipts in 1877; while the cost of locomotive power alone for the excess of passenger train-miles, at 8*d.* a mile, amounted to £80,093, of which about £15,000 was for coal. Although he admitted that very powerful engines were required for particular trains, he was certainly not of opinion that more powerful engines were necessary at present for the general traffic of railways. The trials of the compound engines had been made with heavy and nearly uniform loads, and at high speeds, when the engines had worked economically as far as coal was concerned. These engines would have, however, to take their turns with light and slow trains, of which there were a great many, and then no doubt some of the economy would disappear. Mr. Aspinall had mentioned a case where economical results were obtained by giving a larger cylinder, and increased boiler-pressure. But these engines were always working the same trains, which were heavy, running at a high speed. Once, in the case of goods engines, he increased the size of the cylinders from 17 inches to 18 inches; but he did not find that they were as economical, from the want of sufficiently heavy loads. When working with heavy loads they

M'Donnell. were economical; but when working light loads, which in practice was often the case, they were not. Additional and more accurate information was required, particularly as to the cost of repairs. Under certain circumstances the compound system might be adopted with advantage, or be greatly improved; but he thought present information was insufficient to justify its general adoption. The train-mile was not a perfect unit, particularly on lines which were dissimilar; but for ordinary work it was convenient.

Worthing- Mr. E. WORTHINGTON, in reply, said that the discussion had embraced the results of much practical experience in the working of locomotives, and in many cases had been supplemented by interesting statistics, not only relating to three-cylinder and two-cylinder compound locomotives, but also to many types of locomotives, land and marine engines; and included not only the practical but also the theoretical bearings of the question. Before alluding to the discussion in detail, he should like to allude to one or two points of the Paper, not referred to by any of the speakers. The four-cylinder compound-locomotive should be by no means forgotten, and might even be found to be the most suitable and practical machine for very powerful engines, notwithstanding its additional cost. It might be arranged without coupling-rods, as in Fig. 28, or in the tandem form, either as applied by Mr. Nesbit, on the North British Railway, or like the powerful eight-wheel coupled goods engine working on the Northern of France Railway,[1] having a pair of tandem cylinders 15 inches and 26 inches in diameter on each side controlled by one valve. From information kindly furnished by Mr. Pulin, a French railway engineer, it appeared that this latter engine was originally an ordinary locomotive, and that the cost of compounding it was about £400. During the short time it had been working it had done good service, the valves and cylinder faces had kept in excellent order, the engine had used little oil, and effected an economy in fuel of from 3·20 to 26·4 per cent., according to the point of cut-off. Further, this engine, when compounded, drew loads 12 per cent. heavier than the ordinary engine, and at the same time effected a considerable saving in fuel.

Another point not mentioned in the discussion was the increased use of oil by compound-engines using high-pressures. This might occur where there were more than two cylinders and valve-gears. But as it was only necessary to lubricate the steam once, namely, as it entered the HP. cylinder, it was extremely probable that two-

[1] A description of this engine will be found in Sect. III. of this volume.

cylinder compound engines would use less oil than ordinary engines. Mr.
Messrs. Beyer, Peacock, and Co., of Gorton Foundry, fitted steam lu- ton.
bricators to both high-pressure and low-pressure cylinders, as a precaution, to be used if required. Mr. Pulin explained the additional consumption of oil by the four independent-cylinder passenger engine on the Northern of France Railway (Fig. 28), as due not to the compound system, but to the construction of certain portions of the axle-box. The conclusions drawn from the diagrams (Figs. 35, 36, and 37), as to the better distribution of strains in the moving parts, also pointed to a reduction of friction, and, therefore, of oil required by compound locomotives. Mr. Lapage seemed to have misunderstood the statement (p. 27) relating to the obstruction caused by steam bottled-up in the receiver of a compound steam-engine. Tram-engines working slowly had often to pull up during the interval of one or two revolutions of their own wheels, which did not suffice to clear the receiver of steam. Therefore, on restarting the engine, this bottled-up steam, being beyond the control of the intercepting valve, acted on the wrong side of the large piston, and did not find an exit at the safety-valve till it reached a pressure of about 70 lbs. to 80 lbs. per square inch. This difficulty would be increased if the receiver were made one and a-half time the capacity of the small cylinder, as recommended by Mr. Lapage. The vacuum in the receiver, illustrated by diagram (Fig. 9), and referred to by Mr. Webb, was easily destroyed by a vacuum or air-admission valve. The method of opening the valve (Fig. 39), for that purpose, as described by Mr. Webb, admitted air from the smoke-box, which was apt to contain much dust and ashes from the fire. At Gorton Foundry, a simple method of destroying this vacuum had been adopted, namely, by fixing a light but large automatic air-valve on the receiver, this valve drawing air from a warm and clean cavity between the cylinders. The valve closed by its own weight, but a reduction in the receiver-pressure of 3 oz. per square inch below the atmosphere caused it to lift, and the warm air thus admitted passed through the low-pressure valve and cylinder to the blast-pipe. With regard to Mr. Willans' remarks as to the advantage of heating the receiver-pipes in the smoke-box, it was true that the same heat, if put into the feed-water, would be more useful than if put into second-hand steam which was about to be thrown away; but there could be no doubt as to the practical conveniences of stowing the bulky receiver-pipes round the smoke-box, and the re-evaporation and superheating, which took place within them, was not to be ignored. The heating surface thus exposed to the waste gases of the smoke-

orthing- box, at 600° to 700° Fahrenheit, amounted in an engine with a 16-inch cylinder to about 40 square feet, and with an 18½-inch cylinder to from 45 to 50 square feet. Several speakers had referred to the bad effects, especially with a light load, of water in the low-pressure cylinder, the existence of which he could thoroughly confirm from his own observations made within the smoke-box of a running compound-locomotive, with the door open. Mr. Thornycroft had graphically described it as spray dashing about in the low-pressure cylinder. Steam-jackets might do something to prevent this if the engine could carry the extra weight; but if the cylinders were properly shielded from radiation and convection of air, he thought a better effect was produced than by Mr. Stroudley's revival of the method of placing the valves below, and taking the damp, chilly, exhaust-steam all round the cylinder-barrel in its course to the blast-pipe. Mr. Holden's first comparative trials of the system showed a saving of 14 per cent. in his compound-engines, using an additional 10-lb. boiler-pressure. On the other hand, the Buenos Ayres and Rosario Railway Company, with the same difference of boiler-pressure, namely, 10 lbs. per square inch in favour of the compound-engine, obtained an economy of 20 per cent. in fuel (Table VII), exactly the same size of boiler being used in the simple and the compound engines. Probably the latter remarkable result was partly due to the mode of driving simple engines by the engine-drivers in South America, who, most likely, were not so careful as the more skilled drivers on the Great Eastern Railway. For it was easy to waste through a pair of simple cylinders much steam, which in the compound-engine was necessarily arrested, and expanded by that useful gleaner of power, the low-pressure cylinder. Mr. Holden's more recent trials showed that this saving of 14 per cent. was almost entirely due to the additional 10 lbs. of pressure. Such comparisons of simple with compound locomotives, using the same comparatively low-pressure, were interesting, but of little practical value, because they ignored one of the chief advantages of the compound system, namely, its suitability for dealing with high steam-pressures. That an increase of boiler-pressure must, however, be credited with some economy, where equally skilful drivers were employed, was further shown by the experience of Mr. Aspinall, who obtained a fuel economy of 13 per cent., by simply using heavier engines and higher pressure. But even these figures fell short of the average 18 per cent. saved by the compound system, which enabled these higher pressures to be easily controlled without straining any portion of the machinery. Again, the remarkable saving of more

than 25 per cent., named by Mr. Webb as the result of trials Mr.
extending over four years, was partly due to the pressures used, ton.
which were 150 lbs. and 130 lbs. per square inch for the compound and non-compound engines respectively. The work done by these two classes of North Western engines was regular and not very heavy, and the compound engines employed upon it were admirably suited to their work. The difficulty mentioned by Mr. Holden, of working stopping trains with compound engines, was dwelt upon at length in the Paper, and the necessity for increasing the size of the high-pressure cylinder for such work was clear from an examination of the ideal diagrams (Figs. 11, 12, 13 and 14). The use of one of the various intercepting-valves, enabling boiler-steam to be applied to both cylinders, was a great advantage at starting; but it was of no use in accelerating the speed, nor in climbing a heavy bank. Mr. Joy, in drawing attention to the similarity between the marine- and the locomotive-engine, wished, if possible, to follow the marine practice, by reducing the size of the high-pressure cylinder in locomotives; but Mr. Holden's experience, and the more theoretical considerations to be found in the Paper (pp. 22 and 23), seemed to furnish sufficient objections to the accomplishment of this; for when a propeller was working slowly, it was doing next to no work; but when a locomotive was starting a train, it must be capable of exerting its maximum tractive power. In other words, the "slip" of the propeller at starting might be anything, but the "slip" of a locomotive driving-wheel should be nil. If a locomotive were always working uniformly, a smaller cylinder, and perhaps triple-expansion, might well be introduced. With regard to the remarks of Mr. Webb and Mr. Stroudley, on the estimate of coal consumed in locomotives, it should be explained, that although the annual mileage of express trains might exceed 20,000, and the coal consumption on light trains be less than 30 lbs. per mile, yet the figures quoted were not an unfair average for the purpose of estimating the coal consumed per annum by the average English locomotive.

The deep frame-plates required in two-cylinder compound-locomotives, either with inside cylinders, which were too wide to fit between the frames on the standard or any narrower gauge, or with outside cylinders when the steam-chests project through the frames, no doubt caused increased expense, which was, however, shared to some extent by all outside-cylinder engines of ordinary English patterns. But the great depth of frame-plate required to carry either an outside or inside low-pressure cylinder, was an item which especially tended to increase the cost of that type of

Worthing compound-locomotive. In a large sized two-outside-cylinder compound engine, the additional weight carried on the low-pressure side, due to the larger cylinder, was about 15 cwt., the most important, though not the heaviest, item being the piston which weighed about 135 lbs. more than the high-pressure piston. This disturbing reciprocating weight was reduced in a 16-inch compound locomotive to about 95 lbs., but its influence was somewhat under-estimated by Mr. Lapage, who spoke of little or no difference required for balancing these parts.

Much had been said about the tractive power of compound locomotives. Mr. Adams found coupled express-engines more suitable for heavy traffic than Mr. Webb's 11½-inch cylinder compound engine working with the same boiler-pressure. But the 14-inch cylinder compound, with 180-lbs. boiler-pressure (Fig. 25), would probably do the work easily and with economy. In comparing the relative climbing power of these two classes of locomotives, assuming the average effective pressure in each of the cylinders to be five-sevenths of the effective steam-chest pressure, which could only be the case when working hard at speeds of less than 20 miles an hour, the three-cylinder express-engine, with 14-inch high-pressure cylinders, and wheels 6 feet in diameter, should haul as much as an ordinary engine with 18 by 24-inch cylinders, and wheels 5 feet 7 inches in diameter; and, therefore, this compound engine should haul about 23 per cent. more weight than the ordinary engines with 7 feet wheels, which Mr. Adams now used. It must be admitted, as stated by Mr. Stroudley, that his engine was a better starter and climber than an under-cylindered compound engine; but there seemed to be no reason why an engine could not be constructed on either system, having sufficient cylinder power to slip its wheels, either when starting or running; and if a compound engine were constructed to exert special power when starting, with increased weight on the driving-wheels, or with some other means of increasing their adhesion, this would place the compound engine at an additional advantage.

A compound and a simple engine of nearly equal weight might be constructed to do the same work; but the former would obtain the economy in fuel and repairs which was claimed for the compound system. Mr. Stroudley's engine would probably take a heavier train up a steep grade slowly than most of the two-cylinder compounds yet constructed, because, for obvious reasons, very large outside cylinders should be avoided where possible; but some compound express engines possessing great climbing power, with outside cylinders 18½ inches, and 27 inches in diameter by 26 inches

stroke, had recently been designed, and constructed at Gorton Foundry for the Portuguese Government. They were the largest [1] two-cylinder compound locomotives hitherto made, and were to work on a railway with a ruling gradient of 1 in 55. Mr. Borodine had, however, used larger cylinders in converting an old engine to the compound system. Mr. Thornycroft drew attention to the large cylinder capacity per HP. of existing compound locomotives compared with modern marine, and especially torpedo-engines, naming in particular the Crewe and the North-Eastern Railway locomotives. These latter frequently exerted 1 HP. for every 24 and 21 cubic inches of cylinder volume respectively, a little more perhaps than Mr. Thornycroft gave them credit for. But this large cylinder-capacity, compared with torpedo-boats, was due, not only to the vacuum, and the higher normal speeds of the latter, but also to the occasional requirements of great power in a locomotive at low speeds. The adoption of Mr. Morandière's scheme of using one high- and two low-pressure cylinders (p. 12), and recommended by Mr. Thornycroft and Mr. Willans, would facilitate the reduction of the diameter of the low-pressure cylinders, without affecting their total capacity; but some disadvantage might probably arise from the uneven pressure in the receiver, which would be replenished only twice, while it would be required to supply steam four times, per revolution. This system was yet untried on English railways. A more serious drawback to the compound system in locomotives was the "over-cylindering" referred to on p. 36, and so strongly emphasized by Mr. Reynolds, who gave some interesting information about the method of dealing with this difficulty at sea when large engines were worked below their normal power. It was satisfactory to find that Mr. Willans agreed with the statement (p. 9), that a fivefold expansion was a suitable limit for high speeds, and the inference from this was that a compound locomotive, with a cylinder ratio of 2·1, would be over-cylindered if required to cut off steam at less than $\frac{2}{5}$ of the stroke of the high-pressure piston. This was probably the case during the "race to the North," in August, 1888, referred to by Mr. Reynolds, when the trains on the West Coast route consisted of five coaches only, and were therefore drawn with greater ease by much lighter engines than Mr. Webb's compounds working the heavy North traffic. The "race" trains were worked between Euston and Crewe by single engines, with 16 inches by 24 inches cylinders, and wheels 7 feet 6 inches in diameter, and on the more hilly section north of Crewe, by coupled engines with 17 inches by 24 inches cylinders, and wheels 6 feet 6 inches in diameter. The

Worthing- same compound locomotive was not suited for working both light and heavy traffic, unless its cylinder capacity could be temporarily reduced by some such arrangement as disengaging one or more of the cylinders. A somewhat lengthy part of the Paper had been devoted to the steam throttling in passages and small port-openings. Mr. Reynolds' illustration of the entire loss of the vacuum in torpedo-boats through this cause was a timely warning to constructors of high-speed compound locomotives. The indicator-diagrams on Plate 1 showed that no serious difficulty arose from the later opening of the exhaust-port at high speeds, but the tendency in this direction had been avoided in both three- and two-cylinder engines by giving inside lead to the valves, in some cases of the large low-pressure cylinder, in others of the high-pressure cylinder. The statement as to the heating of connecting-rod bearings, when locomotives were working very expansively, was prompted by the experience of the Author when running with express-trains, and might be due to the early closing of the exhaust, which caused in the cylinders excessive compression, exceeding the pressure on the advancing side of the piston for a considerable distance before the end of the stroke, and thus causing additional detrimental strains and friction in the machinery. Mr. Thornycroft's theoretical argument, founded on the range of temperatures, that Mr. Webb's engine would appear to greater advantage with a little more expansion in the low-pressure cylinder, was met by the same practical difficulty of getting drivers to effect this expansion, although they were able to do so by the ingenious reversing-gear used by Mr. Webb. From the engine-driver's point of view, a more even and moderate pressure throughout the stroke seemed preferable, a result which the compound system realized to a marked degree. The transfer of power from the early half of the stroke to the later half, due to the mass of the reciprocating parts referred to by Mr. Iveson and Mr. Reynolds, was no doubt of great importance at high speeds, in tending to equalize the above-named strains, and consequently the friction in parts of the machinery; but at low speeds this action might be neglected, and at the higher speeds it benefited the compound and ordinary engines alike. The objections to "notching back" a locomotive did not apply merely to the endeavouring to obtain an eight- or ten-fold expansion, but to ordinary 20 per cent. cut-offs; and although English engine-drivers were fast coming to recognize the advantage of a fair amount of expansion, yet men in charge of engines in some remote countries would lose nothing by being compelled to employ a moderate amount of expansion, by adopting the com-

pound system. The remarkable ratio of expansion shown in the indicator diagram, Plate 1, Fig. 3, and referred to by Mr. Willans, might be accounted for, to some extent, by a large amount of re-evaporation in the cylinder, because the diagram was taken immediately after notching the engine back; that was, subsequently to its working with a later cut-off than that shown in the diagram, and therefore both cylinders, and especially the large one, might have been warmer than the steam passing through it at the very low terminal pressure of 8 lbs. The low speed, 21 miles an hour, might also assist in making a full diagram, by affording time for both re-evaporation and also any possible leakage past the small piston. Much of Mr. Willans' running criticism on the rough and ready method adopted in the Paper of illustrating the various principles of compounding and ideal expansion was true; but referring to the statements (p. 5), that it was not the object to discuss these points at length, it would be perhaps out of place to enlarge here on this branch of the subject. The stress laid by Mr. Willans on the importance of reducing the range of temperature in a cylinder, had apparently led him to throw into the background the advantage of the later steam cut-off and larger port-openings. He "would like to know whether, if the valve-motion could be made ever so perfect it would do away with compound engines?" Such a valve-motion would certainly do away with one important advantage claimed for compound over single locomotives, namely, the decrease of steam wiredrawing, but the many other advantages claimed would probably be unaffected by the introduction of a perfect valve-motion. While regretting with Mr. Willans and Professor Kennedy the absence of accurate records of long locomotive runs, and the consequent impossibility of comparing the performance of locomotives working on different railways, or on different sections of the same railway, it must be remembered that the greater number of the comparative results of fuel-consumption given in Table III were the averages of working the same traffic for many months by different engines, and were therefore free from the extraordinary circumstances which were almost sure to attend any one trial, however carefully observed and recorded. The much-abused unit of 1 lb. of coal per train-mile was very reliable when the locomotives compared worked for months or years the same trains, in the same district, with similar coal and water. As had been already pointed out, the engines used in the comparative trials on the Buenos Ayres and Rosario Railway, Table VII and Fig. 23, were fitted with exactly similar boilers, and the compound engine, using steam at a pressure

Mr. Worthington.

of 10 lbs. per square inch above that of the ordinary engine, showed an economy in fuel of over 20 per cent. Professor Kennedy, with his intimate knowledge of measured performances of marine and locomotive engines, regarded some of the marine-engine trials, quoted in the Paper and Table II, as mythical, and without vouching for their accuracy the Author might say that the figures given were from published statements, and the object being to compare them with the best results of locomotive working, he certainly selected the most economical that could be found. Although such results as $1\frac{1}{4}$ to $1\frac{1}{2}$ lb. of coal per indicated HP. per hour had hitherto been reached only with the utmost skill and care on marine-engine trials, they would probably soon become matters of every-day occurrence. The corresponding figures relating to locomotives had also been taken from published statements, with the exception of those relating to the North Western Railway engines, in which the HP. had been estimated from experiments on the resistance of the trains at certain speeds. With regard to Mr. Cowper's remarks about the unfairness of a comparison at maximum power between simple and compound locomotives, showing 35 per cent. in favour of the latter, it should be explained that the instance was specially selected to show the maximum limit of the possible saving, while the majority of examples quoted showed a saving of fuel of about 15 to 18 per cent. While agreeing with the spirit of Mr. Cowper's preference for compound stationary engines over large single-cylindered Corliss engines, it might be well to note that the short statement (p. 8) to which he referred, might perhaps be justified by the greater simplicity and fewer moving-parts of the single-cylindered engine. Without further reference to the many interesting points of the discussion, it might be noted that, if the economical results claimed by the advocates of compound locomotives were obtained in all the locomotives of the United Kingdom, Mr. R. Price Williams had recently pointed out that a saving of 500,000 tons of coal yearly would result. It was not likely nor advisable that any one system of compounding should be applied to all locomotives. Each system had a special feature. Where a locomotive was frequently required to do short spells of extra work, such as climbing steep grades, or making frequent starts, Mr. Mallet's system might be suitable, because in it both high-pressure and low-pressure cylinders could be worked with prime steam for periods as long as the boiler could supply it. In the ordinary main-line work, the Worsdell and von Borries system was extremely simple and suitable, and had the further advantage of being automatic in its compound action. For heavier traffic,

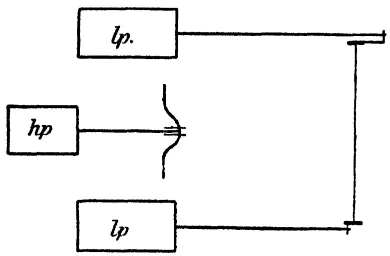
both goods and passenger, Mr. Webb's three-cylinder engines were likely to be employed, and the almost untried three-equal cylinder system gave promise of success. The four-cylinder system, while being complicated, presented advantages of the highest power and uniform well-balanced action. Mr. Worthington.

Correspondence.

Mr. W. H. Booth remarked that, if it was granted that the compound locomotive would supersede the present simple engines for many purposes, there remained to be considered the design which should be adopted. So far as two-cylinder compound engines were desirable, there appeared to be small room for improvement on the design of Mr. Worsdell. As it was only at low speeds that coupled engines had any advantage over single engines, it was clearly advisable to dispense with coupling-rods. Now in the Webb compound engine this was done, and Mr. Webb's engines had the tractive power of coupled engines at low speeds, and also the free running qualities of the single engine at high speeds. There were, however, disadvantages in the Webb compound engine which did not appear insurmountable. Among these was the difficulty in starting, especially should the low-pressure crank be on the dead-point, when the high-pressure wheels slipped on a greasy rail. The next disadvantage was the exceedingly disagreeable surging action for the first twenty seconds or more, after moving from a state of rest. This was distasteful to passengers, and to many had the effect usually associated with travel by water. This effect had been ridiculed; nevertheless it existed. Further, there were disadvantages connected with the manufacture of a larger cylinder, piston, &c., and a multiplication of parts not conducive to economy of make or maintenance. A long experience in compound engines had shown him that it was of the first importance to keep hot the high-, rather than the low-pressure cylinder. The general experience of engineers was rather in favour of multiplying the number of low-, rather than of high-pressure cylinders; neither of these last conditions was carried out in the Webb engine. To remedy all the defects named, he would suggest that the present cumbrous low-pressure cylinder should be superseded by a single high-pressure cylinder of the same diameter as two low-pressure cylinders of an ordinary locomotive, which should be placed outside the frames, in place of the two small cylinders of the Webb engine. Thus all three cylinders would be Mr. Booth.

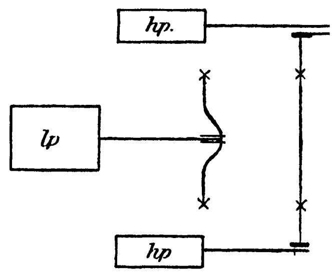
Mr. Booth. of one diameter, and their pistons, covers, and rods interchangeable. Any departure from a cylinder ratio of 1 : 2 would be made by means of a shorter stroke to the inside high-pressure cylinder. With such an arrangement, uniformity in shop work would be attained; the high-pressure cylinder would be kept warm in the smoke-box; the disagreeable surging motion at starting would be so mitigated as to be perhaps imperceptible, whilst none of the advantages now apparent in the Webb engine would be sacrificed. Further, with three cylinders of uniform diameter, the engine could be used as a simple engine, with boiler steam in all cylinders, and in this way would be enabled to perform an enormous duty for a short time, or for such time as the boiler would provide steam. The difficulty in starting would be overcome by the use of boiler steam in the low-pressure cylinders, the high pressure being then allowed to exhaust independently. Certain extra valves would be needed,

FIG. 4.



PROPOSED DESIGN.

FIG. 5.



WEBB TYPE.

but the complication would be less than with the present type and no appliance would be required to keep boiler-pressure off any piston. The proposed arrangement (Fig. 4) would lend itself readily to the conversion of existing locomotives of outside-cylinder type into compound engines, and it seemed to promise all the advantages of both the old simple engines and the present three-cylinder compound engines, with very few disadvantages. The elimination of coupling-rods probably answered for a very large portion of the economy of compound locomotives of the Webb type (Fig. 5).

Mr. von Borries. Mr. A. VON BORRIES remarked that, on p. 17, the Author stated the two compound locomotives, built in 1880 for the Hanoverian State Railways, were on Mr. Mallet's system; but this was not the case, since the engines did not have Mr. Mallet's distributing-valve, but a small hole in the regulator valve-face, by which steam was admitted to the receiver, when the regulator was full open. This

simple arrangement answered well enough for small engines. Also, the link-motion had not separate handles, as in Mr. Mallet's system. The compound locomotives constructed in 1888 in Germany, with two cylinders of equal diameter, but of different strokes, were built for Holland, on the designs of the Locomotive Superintendent, Mr. Middelberg. The Author's objection (p. 21), that the von Borries' method of giving a later cut-off in the low-pressure cylinder than in the high-pressure one would not do with tank-engines, which must run frequently backward, was met by another method which he had devised for such engines, that gave the same result, so far as necessary to get equal distribution of power on both pistons. This method consisted in giving less lap to the valve of the low-pressure cylinder, and suitable construction to the outside parts. In ordinary link-motions, smaller angles to the eccentrics; and in gears like Brown's and Joy's, a smaller head-end of the vertical or reciprocating lever. If the lap of the valve of the low-pressure cylinder was made 0·9 or 0·8 of that of the high-pressure cylinder by the same lead, the proportion of cut-off would be nearly as 40 : 45 or 40 : 50 per cent. in both cylinders, corresponding to a proportion of pistons of 1 : 2·2 or 1 : 2·0. This very simple method had been applied to the Alsace-Lorraine passenger tank-engine, and required only a somewhat larger travel of valve for the high-pressure cylinder to get travel enough for the low-pressure one. As to the tractive force of compound locomotives (p. 22), he recommended that the small cylinder should be equal in size to that of the single engine, if they were to have the same power. If the same boiler was kept for the compound, the high-pressure cylinder must be 1 inch larger in diameter, as proposed by the Author; but then the engine would be more powerful. Many of the compound engines now running would do still better if they had larger cylinders—large enough in proportion to the boiler-power. The gradients of German railways were only favourable in the northern plains; in the middle and southern parts, long and steep gradients were as frequent as in England. In Germany compound locomotives did as well on these heavy lines with low speed, a 39-ton goods engine taking twenty-seven coal-trucks and a brake-van, weighing some 440 tons, up a gradient of 1 in 100, at a speed of 10 miles per hour. He believed the Author was mistaken (p. 36), in thinking the compound system to be less suitable for England than for other countries. As to the cost, compound engines could be built 2 to 5 per cent. cheaper than simple engines of the same power—not of same maximum tractive force, because this power depended upon the boiler, which might be 10 to

Mr. von Borries.

Mr. von Borries. 15 per cent. smaller for the compound engine. If the same boiler was kept, as was commonly the case, the compound engine would be some 2 or 3 per cent. heavier, and 4 or 5 per cent. more costly than a simple one; but, with properly dimensioned cylinders, 10 to 15 per cent. more powerful than the latter. For equal work, the compound engine would thus always be the cheaper engine. For heavy fast trains on the Hanoverian State Railways, the compound engine had effected a great saving in pilot-engines, which were very costly.

Mr. Drummond. Mr. D. DRUMMOND remarked that there was great difficulty in dealing with the question of compounding locomotives, owing to the lack of information as to the conditions under which the comparative tests had been made. It was necessary, in the first place, to know if both boilers were alike, and if the engines were working under the same pressure, with the same round of duty to perform, and provided with the same quality of fuel. Unless this were so, comparisons as to fuel economy could not possibly be accepted. It might be that any economy effected was due to the larger boiler and increased boiler-pressure, and not to the principle of compounding. It was well known that, unless the boiler was sufficiently large to maintain a steady head of steam at full pressure, while the engine was working at its maximum power, there was a great waste of fuel. As an instance, six express engines had been built for the Caledonian Railway ten years ago, having cylinders 18 inches in diameter by 24 inches stroke, and wheels 7 feet in diameter, but of which the boilers were too small for the engines. He had substituted these for larger boilers, and had increased the pressure from 140 lbs to 150 lbs. per square inch; and, without any other alteration, the result was increased efficiency, and a saving of 7 lbs. of coal per train-mile. Then again, comparative statements had been made of the amount of fuel consumed per train-mile by the respective engines, on various railways, without the whole of the facts being explained. As an illustration, take the coal used on the Scotch railways; there was an average difference in the consumption between the "Slamannan" and the "Lanarkshire" of 10 lbs. per train-mile in favour of the former with the same class of engine, and the same amount of work. Take also the London, Brighton, and South Coast Railway, which was often referred to for its economic consumption of fuel, namely, 24 to 30 lbs. per train-mile. This, for the work done, was excellent; but the coal supplied was almost entirely best Welsh; and to compare this consumption of fuel with that of engines on railways north of the Thames, performing almost similar work with Derby-

shire and Yorkshire coal, would be misleading. Therefore, in discussing a question of this nature, all the circumstances should be taken into consideration. He had not been able to reconcile the principle of compounding locomotives as a sound one; for, of all engines, he thought the locomotive was the one least likely to give satisfactory results in compounding, owing to the constantly varying conditions under which it had to perform its work. The only practical experience he had with the compound locomotive was a trial on the Caledonian Railway, with one built on the Worsdell and von Borries principle, by Messrs. Dubs and Co., in 1886, for a South American railway. On that occasion the working of the engine and its consumption of fuel, compared with that of the ordinary Caledonian engines doing the same work, even after making every allowance for the engine being strange to the driver, and not worked to the best advantage, was such as to confirm his opinion of the unsuitability of compounding the locomotive-engine. The 7-foot single Caledonian engine, No. 123, built by Messrs. Neilson and Co., and exhibited at the Edinburgh Exhibition, had run the fast London express train from Carlisle to Edinburgh and *vice versâ*, before and during the whole time of what was known last year as "the race to Edinburgh," and up to the present time had not lost a single journey. And its consumption in the running of this fast train, over gradients well known to be severe for a long part of the distance, had never exceeded 31·6 lbs. of Scotch coal per train-mile; and these were the same trains as worked by the compound engines on the London and North-Western Railway. A four-cylinder compound engine on the tandem system, designed by Mr. Nisbet, of the North British Railway, had been running on that line for nearly three years. It worked at a pressure of 160 lbs. per square inch, or 20 lbs. above that of the engines running in the same link; but it had not shown any advantage over the ordinary engines, and the cost of maintenance and upkeep was in proportion to the greater number of parts. It was fitted with the Joy motion, and was well designed; but the results were not such as to encourage a repetition of the experiment. To test the relative merits of compound engines as against ordinary modern engines, he should be pleased indeed to ask permission of the Directors of the Caledonian Railway to be allowed to make arrangements to enable this to be done, either with the express, passenger, or goods engines of the Company, or both, the tests to extend over a period of not less than one month. This line, with its long and steep gradients between Carlisle and Aberdeen, would be admirably suited for such a trial, and a test like this would

Mr. Drummond.

Mr. Drummond. settle definitely the question as to which of the two descriptions of engine was the most economical in fuel and up-keep.

Mr. Edwards. Mr. R. EDWARDS observed that it was difficult to compare the economical efficiency of compound locomotives with that of certain types of compound stationary and portable engines, as the trials of the former lacked the very important item of the weight of water used, or, say, lbs. of steam per indicated HP. Until accurate trials had been conducted with this point in view, the comparative economy of locomotives must be chiefly confined to themselves, especially since it was doubtful if their indicated HP. was sufficiently accurate, as the power was so variable. In most comparisons of the efficiency of engines, reference was made to the trials of the Royal Agricultural Society; but this reference did not take into consideration the exceptional way in which the trials were conducted, which could not possibly take place in every-day use. For instance, the boiler and cylinder were swaddled, so to speak, in felt or other non-conductor, and every possible care was taken to prevent the escape of heat. The following table gave a comparison of the economy obtained at trials of some engines, compound and simple, several of which were in daily use, and which might be advantageously compared, if possible, with locomotives.

TYPE OF ENGINE.	Steam-pressure per square inch.	Steam used per indicated HP. per hour.	Welsh coal used per indicated HP. per hour.
	lbs.	lbs.	lbs.
Triple Expansion Condensing Marine Engine	165	13·0	1·36
Newcastle R.A.S.E. trials of Compound Portable Engines	140	18·0	1·89
Newcastle R.A.S.E. trials of Simple Portable Engines.	100	20·8	2·18
Cardiff R.A.S.E. trials of Simple Portable Engines	80	22·5	2·37
Compound Underneath Fixed Engines, also Portable Compound Engines, in every-day use	140	22·5	2·37
Traction Engines, when driving machinery in every-day use	115	32·0	3·36
Portable Engines, in every-day use	80	48·0	5·05

The consumption of coal per indicated HP. was taken on the basis of $9\frac{1}{2}$ lbs. of water being evaporated per 1 lb. of Welsh coal, which, in practice, with properly designed boilers, was generally obtained. The compound underneath fixed engine was of a type now largely used, in sizes of 20 to 150 indicated HP., for driving

electric-light machinery, and for many other industrial purposes, the locomotive form of boiler being adopted, the working pressure being 140 lbs., and would pre-eminently be the type of fixed engine that should be used for economical comparison with locomotives, which it nearly approached in general arrangements and proportions, except, perhaps, in piston-speed, which was 360 feet per minute. Mr. Edwards.

Mr. S. W. Johnson said that although at present he had had no experience with compound locomotive-engines, he had watched with considerable interest the results of the working by Mr. Webb and Mr. Worsdell of their respective compound engines. He had no prejudice for or against any particular system or design of engine; but should always be in favour of the design of engine suited to the work it had to perform, which could be proved to do an equal amount of mechanical duty with the least consumption of fuel and at the lowest aggregate cost. To attain this end, comparisons should be made with engines having the same amount of tractive power, with equal working boiler-pressures, and with the same kind and quality of fuel. Comparisons under any other conditions than these were, to his mind, of little value. Great credit was due to Mr. Webb and to Mr. Worsdell for the efforts they had made, and the difficulties they had overcome in compounding locomotive-engines. It would, however, be satisfactory to compare the results obtained with the best ordinary simple arrangement of engine procurable, with those of a compound engine under the conditions he had named. In locomotive-engines increase in boiler-pressure alone had resulted in a considerable saving of fuel when working a given load. About three years ago he constructed a number of locomotive-boilers suited to a working-pressure of 160 lbs. per square inch. These engines, while doing the same work as other engines of the same design in every other respect, but with a boiler-pressure of 140 lbs. per square inch, shewed a saving of fuel of from 3 to 3½ lbs. per train-mile, or equivalent to from 11 to 13 per cent. for the 20 lbs. increase in pressure. The engines had 18-inch cylinders, 26-inch stroke, and four coupled driving-wheels 7 feet in diameter; they worked the London and Nottingham fast trains at speeds of 50 to 53 miles per hour, using ordinary Derbyshire and Nottingham coal. As regarded the working of heavy fast main-line and Scotch trains with the same class of engine, with steam at 140 lbs. pressure per square inch, the average consumption of coal, for a number of engines over a considerable period, was 29·3 lbs. per mile on the Carlisle section with an average of 13⅜ vehicles, and 30·1 lbs. per mile on the Leicester Mr. Johnson.

Mr. Johnson. section with an average of $14\frac{1}{4}$ vehicles. These trains were worked at booked speeds of 48 to 50 miles per hour; and the ordinary coal of the district was used in each case. The results had been extracted from the ordinary shed coal-sheets of the Midland Railway, and included all coal burned by the engines in getting up steam, standing, &c.

Mr. Mallet. Mr. A. MALLET had read the Paper with much interest, and considered it remarkable from all points of view. He only regretted that the Author had not sought to become better acquainted with the actual state of the question on the Continent; he had given much attention to the engines of Mr. von Borries, and had perhaps not sufficiently noticed what had been recently done by others. The Author would soon be able to see, at the Paris Exhibition, types of compound locomotives, of the existence of which he probably had no suspicion. Mr. Mallet would correct some slight errors in the Paper which related only to his practice of some eight or ten years ago, and to begin, protested anew against the assertion that the application of the principle of continuous expansion by Samuel in 1852 was the oldest application of the compound principle to locomotives. No doubt it was the first attempt to modify the ordinary method of the employment of steam; but continuous expansion ought not to be compared with the compound principle. This system did not admit of the two essential points which constituted the advantage of the compound, namely, the reduction of pressure and the differences of initial and final temperatures in each cylinder. The point of departure of Samuel was the following, in his own words:—"It appears that a portion of the steam discharged can be spared from the blast to be subjected to a greater extent of expansion . . . . The economy in the continuous expansion consists in obtaining from such portion of the steam as can be spared from the blast the additional power of expansion remaining in it, which is thrown away in the ordinary engines, ... between half and two-thirds of the steam supplied to the first cylinder is discharged at the pressure required to produce the blast, and the remaining steam (one-third to one-half) is expanded down in the second cylinder, so as to give out all the available power remaining in it." This was not at all what happened in a true compound locomotive, where all the steam which entered the small cylinder passed to the larger, and where it was only the steam exhausted from this large cylinder which served for draught. Why, then, this complicated arrangement, giving only an insufficient and partial expansion, employed by Samuel? Because he, like everybody at the time,

was persuaded that the draught would be insufficient if expanded steam only were employed. When Mr. Mallet proposed, in 1874, the employment in locomotives of two unequal cylinders, working as a true compound engine, it was forthwith objected that the feeble pressure of the escape, and the number of strokes of exhaust, reduced from four to two for each revolution of wheels, would not produce sufficient draught, and that the engine would be deficient in steam.[1] The trial trip made in June, 1876, at Creusot, on the first compound locomotive constructed at those works for the Bayonne and Biarritz Railway, had proved that these fears were unfounded, and that the steam from the large cylinder alone, with two exhausts per revolution, was quite sufficient to secure good draught and ample production of steam. From that time the problem of the compound locomotive was solved, and there were no more difficulties to overcome. Moreover—at least for locomotives with two cylinders—alterations had since been confined to matters of detail, for the locomotives of the Bayonne-Biarritz Railway contained, from the first, all the essentials of actual compound locomotives with two cylinders, such as the proper apparatus for each cylinder, the receiver in the smoke-box, etc. This small line had been the only one worked solely by compound locomotives from the day of its opening twelve years ago. It must be admitted that the system of continuous expansion of Samuel could not furnish any precedent, nor any example for the solution of this problem, which had been the true point of departure of compound locomotives. Mr. Mallet had, indeed, as indicated by the Author, employed many different ratios of volume between the cylinders; but it must not be thought that he had done so of set purpose; many of his compound engines were altered engines, where, to diminish the expense of alteration, one of the cylinders had been preserved, and another of the greatest diameter suitable to the engine, substituted for the other. It was this which had given rise to ratios less than 2 in some of his engines. But beyond the ratio 2·78 for the first three engines of the Bayonne and Biarritz Railway, he had always employed the ratios of 2·25 for small engines, and of 2 and 2·1 for large ones; ratios copied by the majority of engineers who had followed him, especially Mr. von Borries. There was nothing mysterious in the ratio 2·25 employed from 1877 on the two six-wheels coupled engines of the

Mr. Mallet.

[1] Identical objections were made when Mr. Ebenezer Kemp proposed a compound two-cylinder locomotive, in a Paper read in 1876 before the Institution of Engineers and Shipbuilders in Scotland, "On the Compounding of Locomotive and other Non-Condensing Engines." Transactions, vol. xx. p. 31.

Mr. Mallet. Bayonne and Biarritz Railway. It was simply from the ratio of the sections of the pistons whose diameters were 1½ and 1, round numbers, and convenient to employ. He had used the ratio 2·04 since 1879, in the alteration of the engines of the Russian South Western Railways; it was the ratio of the sections of cylinders of which the diameter was 16½ inches, the diameter of the original cylinders of the engines, and of 23½ inches, the largest diameter that the construction of the engine allowed. It was evident besides that the ratio should be near 2, since as it would be a question of comparative trial between the altered engine and the others, it was necessary that the total volume of expansion of the cylinders should remain sensibly the same in the two cases. In regard to the altered engine of the Russian South Western Railways, the reason it had received steam-jacketed cylinders was that it might serve for special experiments in regard to steam jackets; but it was the only engine that had been so fitted, and he had never allowed steam-jackets in his practice, as had been wrongly asserted by several authors. He had at first employed the starting valve (Plate 3, Fig. 38); but he had for a long time substituted, especially for large engines, a less bulky apparatus, with a more direct passage, and automatic action, in which there was a retaining valve like that of Mr. von Borries, but combined with a small exhaust-valve, so that when the steam from the boiler came directly to the receiver, and closed the principal valve, the steam which escaped from the small cylinder passed outside, and did not produce back-pressure. This system had the advantage of prolonging as much as might be desired the period of starting without counter-pressure on the small cylinder, which with the arrangement of Messrs. von Borries and Worsdell was confined to a half revolution of the wheels, or nearly so. Further, great safety was thus obtained, because in case of accident the engine could proceed with one or other of the cylinders alone. The engine could produce the same effect as an ordinary engine in which the two cylinders had the same diameter as the small cylinder of the compound engine, so that if, as the Author said, the maximum effect took place at starting, there would be no need to make the small cylinder greater than the cylinders of an ordinary engine. From this there resulted a marked economy in the conversion of existing engines into compound ones—an operation which Mr. Mallet had carried out on a considerable scale. He had adopted in a certain number of engines a system of reversing-gear,[1] which

[1] Institution of Mechanical Engineers. Proceedings, 1879. Plate 37.

the Author had wrongly described as two independent reversing-gears, for the two gears could be either dependent or independent, like the arrangement of Mr. Webb; it was rather a sort of differential motion. As, with this system, engine-drivers could make a mistake, and not give to the cylinders the best relative cut-off, Mr. Mallet had for several years substituted an automatic arrangement which regulated, without the intervention of the driver, the cut-off to the two cylinders, after a rate similar to that of Mr. von Borries's, but avoiding the inconvenience, justly marked by the Author, of sacrificing the back stroke to the forward stroke. In this arrangement, both very simple and very efficacious, the relative cut-off to the two cylinders was the same before and behind, and the dead centre was common. This arrangement would be seen at the forthcoming Exhibition in Paris in a large compound locomotive for the French State Railways. Mr. Mallet had always approved of two rather than of three or four cylinders for a compound locomotive, as it led to greater simplicity and less weight, and the cooling surface of the cylinders, by contact with which the condensation of steam and re-evaporation were produced, causes of injurious loss of caloric, were thereby reduced to a minimum. Two cylinders were sufficient in nearly all cases. Mr. Borodin had recently altered locomotives to compound engines with four axles coupled, by substituting for one of the cylinders 19½ inches in diameter another of 28 inches. These dimensions were almost exactly the same as had been given ten years ago by Mr. Mallet,[1] just as some others[2] very closely resembled those constructed recently by Mr. Worsdell. Mr. Mallet was likewise of opinion that if more than two cylinders were employed, an attempt should be made to realise something more than the compound principle, and to take advantage of the supplemental cylinders to suppress the connecting-rods, as Mr. Webb had done, or to distribute the weight of the engine over a greater number of axles, and to give flexibility to the whole, as he had himself done in the system of articulated locomotives, of which a considerable number had already been constructed. These engines were of great convenience on narrow-gauge lines, particularly on Decauville's portable railways. He might instance the interior railway of the Paris Exhibition of 1 foot 11½ inches gauge, with rails weighing 19 lbs. per yard, on which travelled engines of 12 tons with four driving-axles. These engines were much more simple than the Fairlie engines, and traversed curves

Mr. Mallet.

[1] Institution of Mechanical Engineers. Proceedings, 1879. Plate 40, Fig. 14.
[2] *Ibid.*, Figs. 11 and 12.

Mr. Mallet. of like small radius. They possessed the great advantage over the latter in that the high-pressure piping was fixed as in ordinary engines, and that there was only a single turning-joint, establishing communication between the two groups of cylinders, and only containing steam of 50 lbs. pressure or thereabouts. There had also been constructed for metre-gauge lines engines on the same pattern, weighing 24 to 30 tons when equipped, and engines had been designed for the normal road with six axles weighing 80 tons. Mr. Mallet did not share the opinion of the Author that the maintenance of compound locomotives would be necessarily higher than that of ordinary locomotives. The kind of engine must evidently be taken into account. If this was a two-cylinder engine there was no reason why the maintenance and the lubrication should be greater, but the contrary. There were not more steam-joints, and the half only of the joints were high-pressure. The slide-valves had less load to bear and were less worn. Mr. Mallet had for a long time maintained, supported by his own experience, that the true way of making a balanced slide-valve as simple as an ordinary valve was to compound the engine. As to lubrication, he would cite the following instance. For seven similar goods locomotives, except that one of them had been altered to a compound, of which in the last three months of 1888 the mileage had been altogether 43,740 miles (72,000 kilometres) on the Western of Switzerland Railways, the average consumption of lubricants had been 0·097 lb. per mile (0·0274 kilogram per kilometre), the compound engine had expended 0·089 lb. (0·0252 kilogram), the least consumption had been 0·081 lb. per mile (0·0227 kilogram per kilometre), but as the compound had a total load 4 or 5 per cent. higher than the engine which had consumed least, it might be said that the expenditure for the two engines had been practically the same. Anyhow, there resulted a less expenditure on the compound than the average of the other engines. If the engines had three or four cylinders and as many gears, the expenses of lubrication and of maintenance would necessarily be slightly raised, but if these arrangements had, as indicated above, the object of securing certain advantages for the engine, besides working compound, these advantages might more than compensate the excess of expenditure for lubrication and maintenance, which excess should not be exaggerated. Thus he would cite one of his articulated engines for a metre gauge, which, compared with ordinary engines of the same weight, used nearly one-third to one-half more lubricant, but as the former drew, for a like weight, a load 150 per cent. heavier, or drew an equal load with an economy of 20 per cent. at least of

fuel, this excess of the cost of lubricant could be tolerated, particularly if account was taken of the fact that the compound engine, thanks to its articulated construction, did not unduly wear its tires on curves of 328 feet (100 metres) radius, and tried the line much less than ordinary engines. It was right, moreover, to say that the increased expenditure on lubrication in this case was not entirely due to the adoption of the compound principle, but suited the general plan of the engine, of which the object was to secure other advantages than the economy of fuel. Mr. Mallet.

Mr. J. MANSON observed that balanced slide-valves had been in use on the Great North of Scotland Railway for over twenty years. Forty-one outside-cylinder and fourteen inside-cylinder engines were at the present time fitted with them. Inside cylinders, with the valve-casing between them, were fitted with a division plate on which the balance rings worked. Nine new inside-cylinder engines built in 1888 had the cylinders cast together, the balanced valves being placed on the top. These were worked by a special arrangement of the link-motion, in which the front end of the valve-rod carried a small die-block, for working the lower end of a rocking arm moving freely on a fixed shaft carried by the motion plate; the upper end of the rocking arm was connected to the valve-spindle by a link. This arrangement had given entire satisfaction, and the valves worked with so little friction, that the drivers could easily notch up the reversing-lever when the boiler-pressure was 150 lbs. per square inch, and the regulating valve full open. Mr. Manson.

Mr. W. MARRIOTT remarked that the Author seemed rather uncertain as to the extra capital cost, as well as whether there would be any extra charge under the head of repairs and renewals, by the adoption of compound locomotives. It would be interesting to learn if the compound engines ran with the same allowance of oil per 100 miles as the simple engines. Until some definite information was given on these points, it would be difficult to determine at what point in the price of coal compounding would be an economy, the Author rightly admitting that there were instances where the economy estimated would not pay for the extra cost of the compound engine. Although the Webb system seemed to have advantages which the Worsdell system had not, yet as a simple engine was so adaptable to the Worsdell type, this would seem to be the most adapted for alterations. On many lines, where the capital account was virtually closed, an alteration to the latter system could be effected at a comparatively small expense. Mr. Marriott.

Mr. Stirling. Mr. JAMES STIRLING stated that he had not yet seen any results, obtained by compound locomotives, which could induce him to recommend their adoption on the South Eastern Railway. Considerable economy of fuel had been claimed for them on the London and North Western, and the North Eastern Railways. But on other railways compound locomotives had not been able to do the work so well as ordinary engines, nor had they been able to do it so economically. He believed he was right in saying that these remarks applied to the trials on the Manchester, Sheffield, and Lincolnshire, the London and South Western, and Metropolitan Railways. In 1873, while locomotive engineer of the Glasgow and South Western Railway, he designed a 7-foot coupled-engine, having a bogie in front, with inside cylinders, 18 inches in diameter by 26 inches stroke, and the valves between; and he was so much pleased with the results, with a steam-pressure of 140 lbs. per square inch, that he continued to build engines of this class so long as he was with that company. He might thus be considered an early exponent of the advantages of large cylinders for locomotive-engines. In 1883, he further increased the diameter of the cylinders to 19 inches, and there were now a large number of engines with cylinders of this size running on the South Eastern Railway, showing the most satisfactory performances, and doing some very heavy work. The following results had been obtained from a gang of six of these engines, stationed at Dover, working mail and express trains between London and Dover. The engines changed trains daily, and each ran about 1,000 train-miles per week. The steam-pressure was 150 lbs. per square inch. All the fuel used in lighting up, shunting, and light mileage was debited to the train-miles. Three months, at different seasons of the year, gave, he thought, a fair idea of the influences of weather, load, and working generally. *May*, 1887.—Average load, twelve vehicles, 120 tons; engine and tender, 70 tons. Total load, 190 tons; fuel 27·62 lbs. per train-mile. *August*, 1887.—Average load, fifteen vehicles, 152 tons; engine and tender, 70 tons. Total load, 220 tons; fuel, 28·70 lbs. per train-mile. *November*, 1887.—Average load, twelve vehicles, 120 tons; engine and tender, 70 tons. Total load, 190 tons; fuel, 30·37 lbs. per train-mile. He should like to test one of Mr. Webb's or Mr. Worsdell's compound engines alongside one of his large-cylinder engines for a month, under the most careful supervision, burning the same kind of fuel, and his engine working at the same pressure as the compound. In this way a comparison between compound and large-cylinder engines could be obtained, which, he felt sure, would satisfy the minds of locomotive engineers

who were in doubt as to the advantage of compounding locomotives.

Mr. ROBERT WILSON observed that, according to the Paper, the adoption of the principle of compounding to locomotive-engines had effected a saving of fuel to the extent of 15 to 20 per cent. upon that consumed by high-pressure locomotives doing equal duty. Such results were quite as favourable as most engineers versed in locomotive and general engine practice would anticipate, taking into consideration the conditions under which a locomotive performed work, which were widely different to those giving most favourable results in the case of pumping, mill, or marine compound engines. These were usually at work during comparatively long periods of uninterrupted motion combined with a steady velocity, and developed a given power, for which was designed the relative sizes of the high and low-pressure cylinders, together with the period of cut-off in each. The conditions under which a locomotive was called upon to work were very different; there were the frequent stoppages, with possible variation of speed between each; the exigencies of traffic, which on many lines might necessitate a considerable difference of loads to more or less than the normal; and the different gradients on the line, over which the engine had to travel, might be such as would necessitate a wide variation of power between the minimum and maximum. To many it would no doubt appear a difficult problem to design a compound locomotive to work equally advantageously when subjected to these varying conditions, and many questions, raised by theory, would have to be answered by practice. One of these was, whether it was possible, by the present arrangement of valve-motion, to obtain an equal power from the high and the low-pressure cylinders, and to maintain this equal power throughout all changing conditions? If this was not possible, then he thought the two-cylinder compound engines might be subject to a lurching action, which might set up an oscillation which at high speeds might affect the cost of maintenance of the engine and of the permanent way. The three-cylinder compound engine should be free from this defect, as the two outside cylinders would balance each other, being both high-pressure; and the strain from the low-pressure being central with the engine, would be neutral with respect to any oscillation; any difference in power, between the high and the low-pressure cylinders, might be absorbed in slips, or be productive of slight jerks imperceptible at high speeds. It was, therefore, probable that the maintenance of the two systems would be much the same, as the extra cylinder in the one would com-

Mr. Wilson. pensate any increased cost, due to rolling in the two-cylinder type. It was quite probable that compound engines might prove more economical than high-pressure engines, when compared upon the duty demanded from them upon lines in this country, together with the prices paid for skilled labour, materials for repairs, and fuel; and the results showed still more favourably with low charges for maintenance combined with exceptionally high cost of fuel. But it was reasonable to suppose that conditions might exist, where the saving in fuel would be more than absorbed by the increased charges against maintenance and capital: for instance, the New Zealand Government lines. In that colony the cost of skilled labour and manufactured materials was very high, combined with coal at a comparatively moderate price. The New Zealand Public Works statement for the financial year, March 1887 to March 1888, showed an expenditure on fuel of £34,434, and upon the maintenance and renewals of locomotives of £54,466, with a train-mileage of 3,008,948, being equal to 2·98*d.* per train-mile for fuel, and 4·10*d.* for maintenance and renewals, making fuel and maintenance together equal to 7·08*d.* per train-mile. Without specific data it was impossible to arrive at a true comparative estimate of the cost of working two different types of locomotives; but an approximate idea might be gained by assumptions which would, possibly, not be far wide of the truth. Taking for comparison the three-cylinder compounds, it might be assumed that the increased cost of maintenance would be caused by an extra cylinder, valve and motion, piston and rod, reversing-lever connections, connecting-rod, &c.; but as no coupling-rods were required, the connecting-rod, single-throw crank, steam-pipes, &c., might be set off against these. To arrive at the details of maintenance, not having them separated on the New Zealand lines, he would take those upon the New York Central and Hudson River Railroad, as being nearer the conditions in New Zealand than any English main line:—

	Per cent.
Motive machinery	33·9
Wheels, tires and axles	11·8
Bogie, smith work, &c.	18·3
Boiler tubes, &c.	26·1
Woodwork, fittings, &c.	4·7
Painting	5·2

Then 33·9 per cent. of 4·1*d.* = 1·6359*d.*; taking $\frac{1}{3}$ instead of $\frac{1}{2}$ extra maintenance on motive machinery for the extra cylinder and fittings = 33 per cent. of 1·6359 = 0·539 + 4·1 = 4·639*d.* for new maintenance. Fuel per train-mile less 15 per cent. saved

by compounding = $2 \cdot 98d. - 0 \cdot 447$, new fuel cost $+ 2 \cdot 533d.$; this $+ 4 \cdot 639d.$ new maintenance $= 7 \cdot 172d.$, against the present figure $7 \cdot 08d.$, which was unfavourable to the compound locomotive, without taking into account the interest on extra cost of the new type of engine, or any extra maintenance due to increased pressures. Such an assumed comparison, though possibly of little practical value, might serve the purpose of pointing out, to those most interested in the introduction of the compound principle to locomotive-engines, that it was to their interest to afford trustworthy data, upon which such a comparison as the above might be based. Engineers in general, more especially those interested in locomotive practice, would look forward to, and welcome the publication of, details which would not only show the saving of fuel, but also the comparative cost of maintenance and capital charges of compound and high-pressure engines. Mr. Wilson.

Mr. E. Worthington, in reply to correspondence, remarked that Mr. Booth might be right in advocating the three-cylinder system with one high-pressure and two low-pressure cylinders, but some of his reasons for so doing were not very convincing. Would not the single unbalanced high-pressure cylinder, taking its steam direct from the boiler, be apt to aggravate rather than to "mitigate" "the disagreeable surging motion at starting?" It acted immediately the engine commenced to move, whereas Mr. Webb's unbalanced low-pressure cylinder did not usually come into full action until the engine had moved about its own length. Again, it was well known that in compound locomotives running with a light load, the high-pressure cylinder or cylinders did by far the greater part of the work. In the three-equal-cylinder engine this would be done by the single unbalanced cylinder, but in Mr. Webb's engine it was done with greater uniformity by the pair of high-pressure cylinders. It would probably be found advisable, in the three-equal-cylinder engine, to cut off steam in the low-pressure cylinders earlier than in Mr. Webb's engine, and this could be accomplished with reversing-gears at present in use, if no further difficulty were met in getting rid of the exhaust-steam. The advantage of this engine over the two-cylinder compound, in the interchangeability of its parts, would not extend much beyond the piston-heads; for in the existing two-cylinder compound engines the piston-rods, back-cylinder covers and machinery were the same for both high-pressure and low-pressure engines. In the proposed engine, if the machinery of the two low-pressure engines were made duplicate with that of the high-pressure engine, as recommended by Mr. Booth, they must all three be made capable Mr. Worthington.

Mr. Worthington. of resisting the boiler-pressure on their pistons. But this would render the low-pressure engines clumsy for their common duty. It was not clear why any very large proportion of the economy in compounding was due to the absence of coupling-rods; for this economy, in fuel at any rate, had followed the adoption of both two-cylinder and four-cylinder compound engines, all of which had coupling-rods. Again, the valves required to start the three-equal-cylinder engine would be more complicated than those for the Webb engine, and, when all was considered, the chief superiority of the engine recommended by Mr. Booth appeared to be the avoidance of very large cylinders. Mr. von Borries, in referring to the cost of simple and of compound locomotives, was comparing engines of the same tractive power at high speeds, when the boiler of the compound engine might be 10 to 15 per cent. less in size. One of the great advantages of the system applied on the North-Eastern Railway was found to be the heavy trains which these engines could take at high speeds, compared with ordinary engines of equal boiler-power, and hence arose the very large HP. daily indicated by Mr. Worsdell's engines. But when climbing at low speeds, the compound engine required the additional cylinder-power described on p. 24, and, the blast being softer, it was doubtful whether a boiler 10 to 15 per cent. smaller than that of a simple engine would supply enough steam for this larger cylinder. It was for this reason that the Author compared the tractive power at low speeds in estimating the relative cost. Mr. Drummond's experience of the value of large boilers and his statements of the impossibility of making exact comparisons between engines working on different railways were interesting, but they hardly affected the arguments relating to compound locomotives. In no case, in Table VII of the fuel-consumption of compound locomotives, had the performance of an engine on one railway been compared with the performance of an engine on another railway. In order to make accurate comparisons between one type of engine and another, all variable local conditions should be eliminated as far as possible, and to do this careful treatment in an exceptional manner was necessary. Moreover, the locomotive was so different from any other type of engine, that even such comparisons would not be of much practical value, however much light they might throw on the general question of steam-engines. The comparison proposed by Mr. Edwards, between the compound underneath fixed engine and the compound locomotive, would be of this character, inasmuch as the average HP. of a locomotive was from 400 to 500, and its piston-speed often reached 1,000 feet per minute—a power and a speed never

attained by the fixed engine. Mr. Johnson's experience further confirmed the conclusion that considerable economy in fuel could be obtained by increasing the boiler-pressure in simple engines; but, even on Mr. Johnson's own showing, the amount of that economy was only about two-thirds of the average of the savings of compound locomotives enumerated in Table VII. It was unfortunate that the trials of three-cylinder compound locomotives on the London and South-Western and the Manchester, Sheffield and Lincolnshire Railways were not made with engines as powerful as those daily working the trains; but this should not stand in the way of an unbiassed judgment between equally powerful engines doing the same amount of work. Mr. J. Stirling possibly referred only to the disagreeable motion on starting, when he stated that compound locomotives had not answered so well as ordinary engines on the Metropolitan Railways; for on the outer circle Mr. Webb's compound engine was working the traffic with an expenditure of coal and water about 25 per cent. less than that of the other engines. This saving was of more value, in a city traffic, than the mere cost of fuel and water. It was perhaps unnecessary to point out that Table VII contained particulars of about twenty railways on which compound locomotives had succeeded in effecting an economy of fuel. The problem named by Mr. Wilson had been solved on the North-Eastern Railway, where Mr. Worsdell had taken large numbers of indicator diagrams from his express and goods engines at several speeds, and points of cut-off, which showed that the HP. developed in each cylinder was practically the same. Mr. Mallet's system of compounding, the more recent developments of which had not received adequate notice in the Paper, were described in his interesting communication, and the Author was indebted to Mr. Mallet for some additional particulars of Continental engines, placed at the end of Table I, which thus now contained a list of about five hundred and sixty-nine compound locomotives.

Mr. [Worthing]ton.

15 and 22 January, 1889.

SIR GEORGE B. BRUCE, President,
in the Chair.

The discussion on the Paper, by Mr. Edgar Worthington, on "The Compound Principle Applied to Locomotives," occupied both evenings.

29 January, 1889.

Sir GEORGE B. BRUCE, President, in the Chair.

(*Paper No. 2375.*)

"The Trincheras Steep Incline on the Puerto Cabello and Valencia Railway, Venezuela."

By John Carruthers, M. Inst. C.E.

The Puerto Cabello and Valencia Railway of Venezuela offers an interesting comparison of the two different methods of setting out lines of railways in mountainous countries, namely, that of adopting a nearly uniform gradient in order to surmount a high summit, or that of keeping the line as long as possible in the valley, and overcoming the ascent by means of steep inclines. A description of the line may therefore be interesting, although, apart from the inclined plane which was adopted, the works presented no difficulties beyond those always met with in mountainous countries.

The interior of Venezuela is cut off from the Caribbean Sea on the north by a range of mountains, which has now been crossed by two lines of railway. One of these, 23 miles in length and with a summit-level 3,500 feet above the sea, connects Carácas, the capital of the Republic, with the port of La Guaira; the other, the line under discussion, is 34 miles in length with a summit-level of 1,950 feet. It connects Valencia, the capital of the State of Carabobo and the second city of the Republic, with the excellent harbour of Puerto Cabello.

The La Guaira line was built with, as nearly as possible, a uniform gradient of $3\frac{1}{2}$ per cent. and with a continuous succession of curves of 140 feet radius. Even with these sharp curves the works were very heavy, and as the mountains consist of clay slates and mica schists much broken and disintegrated, the maintenance of the line has been costly, on account of slips occurring in the slopes of the cuttings during the rainy season.

The surveys of the Puerto Cabello and Valencia Railway were begun during the construction of that from La Guaira to Carácas,

with the view of commencing the former as soon as the other was finished, and the line was completely set out, full plans, sections, and cross-sections having been made. The principle adopted in setting out the line by the Engineer, General J. C. de Castro, was that of making the gradient as nearly as possible uniform from the sea-level at Puerto Cabello to the summit. The Author, who happened to be at the time in Venezuela on a professional visit, was invited by General Guzman-Blanco, the President of the Republic, to examine and report upon the line thus traced out, and for the construction of which it was intended to at once form a company. On his recommendation General de Castro was instructed by the Government to continue his studies, and to survey a new line, adopting the principle of getting down from the summit as quickly as possible by means of a steep incline, and then following the valley bed. Two sets of surveys were accordingly made, one with a gradient of 5 per cent. with the view of using ordinary locomotives, and the other with a gradient of 8 per cent., on which, of course, some special mode of traction would be necessary. The latter line appeared to the Author to be superior, not only to the former, but also to the original line with a uniform gradient, and on his recommendation it was adopted, and the railway has been constructed upon it. The very rare opportunity is thus afforded of comparing two lines between the same points, which have both been fully set out on the two opposite principles of design.

Plate 4 shows the plans and sections between Puerto Cabello and La Entrada, of the original line with uniform gradient, and of the line as constructed with an inclined plane; the remaining distance of 9 miles from La Entrada to Valencia being common to both, and not possessing any peculiarities worthy of note, is not shown.

The line with uniform gradient may, for the sake of brevity, be called the "Guaiguaza," line, and that with the inclined plane the "Palito" line. In making a comparison between them, regard must be paid to the three points of:—1. Original cost. 2. Maintenance of way and works. 3. Locomotive expenses.

Original Cost.

The Guaiguaza line would have been very much more costly than the other, the country through which it passes being extremely rough, the contours very irregular, and the general slope of the hills not flatter than 2 to 1. The cuttings and

embankments would have been seldom less than 30 or 40 feet, often attaining to 100 feet on the centre line; these quantities, of course, representing such a depth on the down side of embankments, and on the up side of cuttings, as would necessitate the use of many viaducts in the one case and of heavy retaining walls or tunnels in the other. Indeed, the cost of the railway would have been so great as to prohibit its construction, and would have been more than double that of the line adopted. Even, therefore, though a considerable increase in the working expenses had been anticipated, the Author would have considered himself obliged to recommend the adoption of the Palito route.

Maintenance of Way and Works.

It is known from the experience gained on the La Guaira and Carácas Railway, which passes through a precisely similar country and is subject to the same climate, that the Guaiguaza route would have been liable to constant landslips, and might have been blocked several times every rainy season, thus not only being costly to maintain, but productive of serious inconvenience to the public. In order to guard against accidents to the trains, a number of men would have to be kept solely for the purpose of watching the cuttings and of signalling the trains whenever a slip occurred or was likely to occur; nor would it have been possible to avoid all this expense by sloping back the cuttings, for, apart from the cost of doing so, the steepness of the hillsides is so great, that it would be impossible to carry the slopes back to the angle of repose, and the broader surface, exposed to the disintegrating action of the air and rain, would be as likely to increase the slips as to lessen them.

On the Palito route the danger of slips is greatly lessened, and, indeed, almost entirely removed; for, owing to the formation-level being close to the bottom of the valley, the line may be, and is, kept further out from the hillsides than would be possible where, owing to the steepness of the latter, the toe of an embankment would find no support until it reached the valley bed. This advantage will always be obtained on steep hillsides when the level of the railway is kept close to the valley; but there was a further advantage in this particular case, that the rocks are more solid in the lower levels, changing, indeed, in the section between Trincheras and Castano into hard granite, and not, therefore, being liable to slips of any moment.

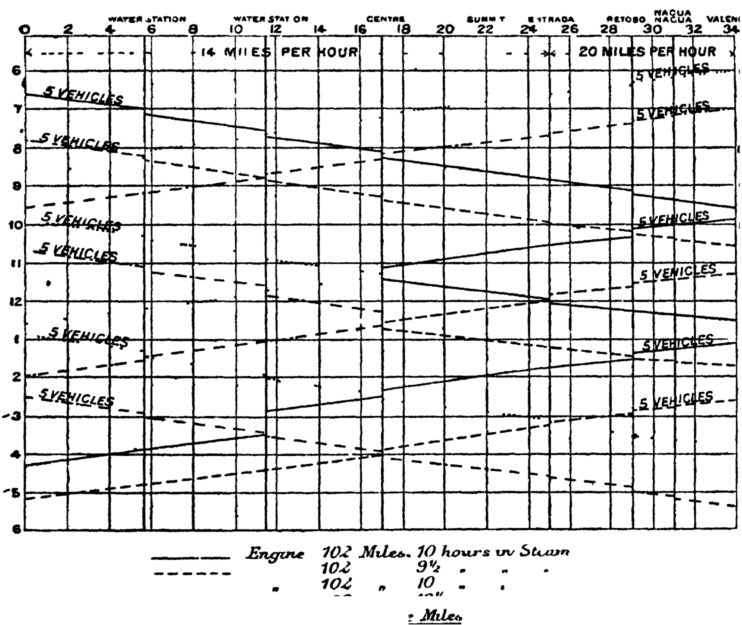
A further advantage on the Palito route is that the curves,

obtainable at an expense within the resources of the railway, are much better, as will be seen by comparing the plans. This advantage tends, of course, to economy in the maintenance of way and works. Taking all these matters into account, when considering the relative advantages and disadvantages of the two lines, the Author came to the conclusion that the Palito route was as much the better of the two in regard to maintenance of way and works as in regard to first cost.

Locomotive Working.

The Palito line being thus greatly superior to the other, on the

Fig 1



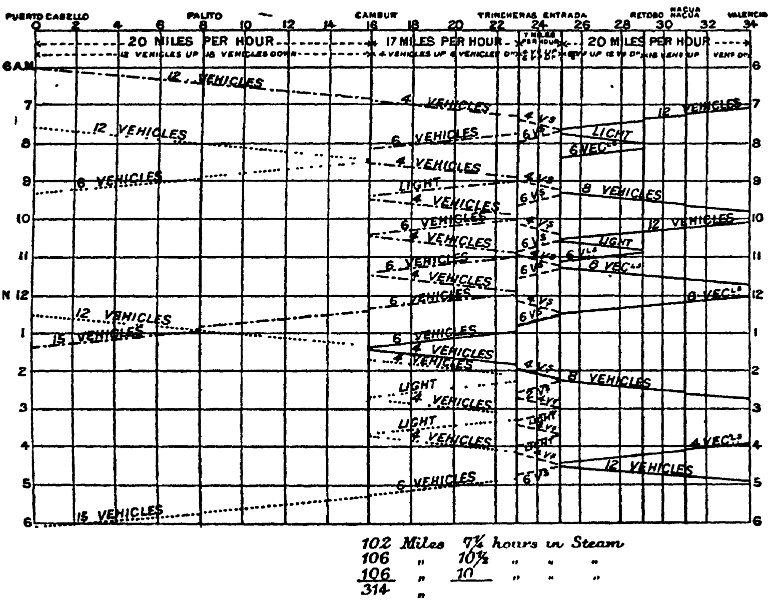
scores of original cost and of maintenance of way and works, could afford to be inferior on the score of locomotive expenses, the saving in interest on first cost alone being probably three or four times the entire estimated amount of the latter. Instead, however, of being inferior, it is really somewhat superior in this respect also, and is capable of handling a greater traffic than the other with the same engine-power, and of carrying passengers safely and economically at a higher average rate of speed. In order to show how this comparison has been made, a time-table for each line is submitted.

demonstrating what could be done with four engines in steam, working steadily for the whole day, without any shunting work at the terminal stations.

By a strange coincidence the length of the two lines is the same within 100 feet, the distance saved on the Guaiguaza line, by avoiding the great bend made by the other at Palito, being exactly lost by the greater amount of curvature.

On the Guaiguaza route, thirty vehicles each way daily, equal to 300 tons a day (Fig. 1), or a traffic of 90,000 tons a year each way, and on the Palito route thirty-six loaded vehicles each way,

FIG. 2.



equal to 360 tons a day (Fig. 2), or a traffic of 108,000 tons, could be carried. The number of engine-miles run in the day would be, for the Guaiguaza route 408, and for Palito 350. The time occupied between the terminals for passengers would be two-and-a-quarter hours for the Palito and two hours and three-quarters for the Guaiguaza.

By adopting the Palito route, therefore, the carrying capacity increased 20 per cent., the engine-mileage reduced 14 per cent., the speed increased 17 per cent. This comparison of the speed

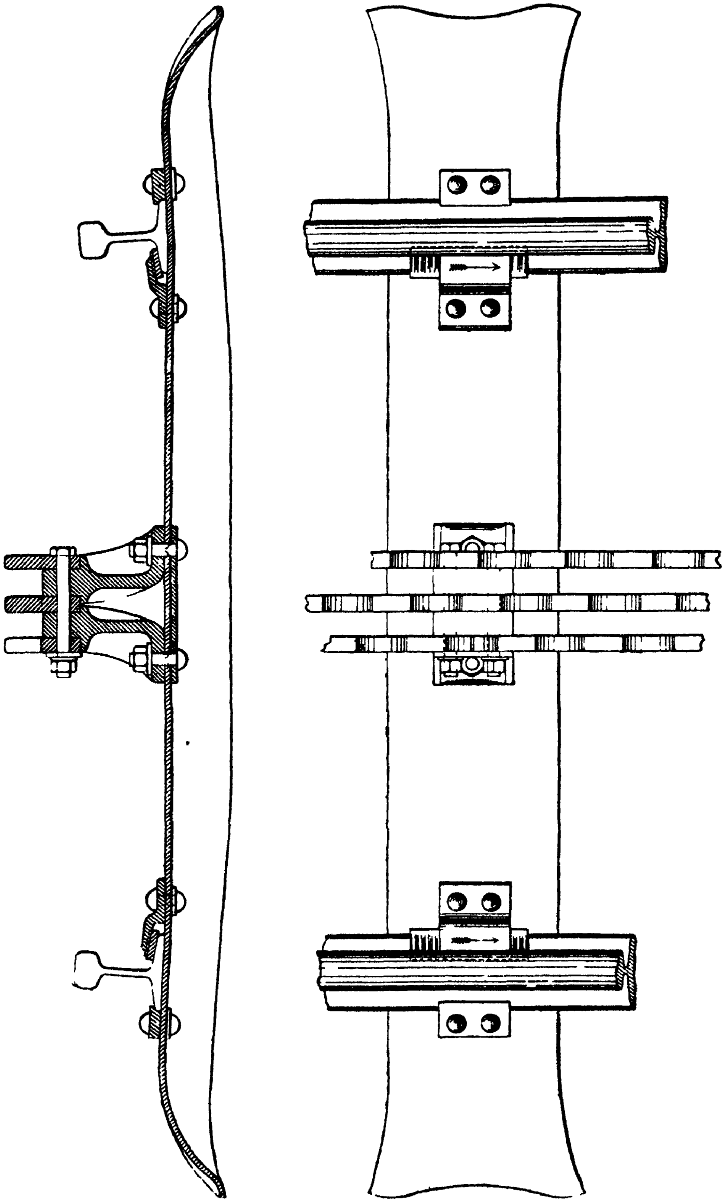
and loads of trains is founded, as far as the Palito route is concerned, on the work done by the engines in every-day practice. The key to the line is the section between Cambur and Trincheras, where the gradient is 3½ per cent. and the minimum curve 300 feet radius. The engines take up this bank four wagons carrying 10 tons each of goods, and maintain a speed while running of 17 miles per hour. On the Guaiguaza line the gradient would have been 2½ per cent., and if no account be taken of the curves a similar engine would convey five-and-a-half wagons. In making the comparison, however, between the two lines, it has been assumed that the extreme crookedness of the Guaiguaza route would reduce the load carried from five-and-a-half to five wagons, and the speed from 17 to 14 miles per hour, an estimate which is certainly not unduly favourable to the line as constructed.

The general method adopted for working the up traffic is that an engine leaves Puerto Cabello in the morning with a full load, and experience shows that it can take twelve wagons to Cambur. Eight wagons are left at Cambur, and four taken up the bank to Trincheras, where they are placed in front of the rack-engine, and taken by it up the incline to the summit at Entrada. The engine, as soon as it has placed the wagons in front of the rack-engine, returns to Cambur, and brings up another set of four, placing them again in front of the rack-engine which has by that time come back down the incline. This process is continued, until the whole train with which the engine left the Port in the morning has been taken to the summit, when the engine returns to the Port having done its day's work by running 102 miles, and having been seven-and-a-half hours in steam.

The several return trips of the ordinary and of the rack-engines are not made light, as the latter engine brings down from the summit to Trincheras, and the former from Trincheras to the Port, the down goods which a third engine had brought from Valencia. The remaining traffic of the day is worked in the same manner, the wagons being taken up, as in the other case, in several trips from Cambur to the summit, and thence into Valencia by the Valencia engine.

The Author had intended to work the incline by engines on the Fell system, the extra adhesion required being obtained by pressing two pairs of horizontal wheels against a centre double-headed rail placed on its side. This system was adopted in New Zealand on his recommendation about fifteen years ago, and has been in steady work ever since, proving in practice to be a sound mechanical contrivance for overcoming steep gradients. Messrs.

Figs 3



Scale $\frac{1}{1}$

James Livesey and Son, the Consulting Engineers of the Company formed for the construction of the Puerto Cabello and Valencia Railway, decided, however, to adopt the rack system as improved by Mr. Abt (Figs. 3). In this system the rack consists of three parallel plates, placed $1\frac{9}{16}$ inch apart, and bolted firmly together; each plate is a complete rack, and they are laid breaking joint both as to the ends of the plates, which are all of the same length, and also as to the position of the teeth. The two pinion-wheels, on the engines which work into the rack, are formed each of three toothed rings, one for each rack-bar. They are laid together with the teeth of one ring leading those of the next by the amount of stepping or overlap in the teeth of the rack. The rings have an elastic connection with the shaft, with the view of correcting any inaccuracies due to imperfect workmanship, or to the expansion and contraction of the rack-rails. This breaking joint of the rack-bars greatly lessens the blow felt in the old ladder-rack system; and in practice no jar is noticed, even when the engine is running at a speed of about 15 miles per hour.

The engines used by Mr. Abt on the Hartz Railway, and elsewhere, are all built on what is called the combined rack-and-adhesion plan, the carrying wheels of the engine being worked as in an ordinary locomotive by one pair of cylinders, a second pair working the two pinion-wheels, which are coupled together. Those adopted by Messrs. James Livesey and Son, for the Trincheras incline, dispense with adhesion altogether, working only through the rack. They were constructed under the patents of Messrs. Lange and Livesey, and, besides being less complex, have several points of superiority over the combined type of engine. The two pinion-wheels are not coupled together as in the latter, but are each actuated by a separate pair of cylinders, an arrangement which ensures that both pinions shall fully press against the teeth of the rack, notwithstanding any slight irregularities in the latter. There are two cylinders on each side of the engine, placed one above the other, and they are so arranged that the same steam-chest, slide-valve, and valve-motion serve for both. The two lower cylinders actuate the leading, and the two upper the trailing, pinion-wheel. There are three independent brakes on the engine; an ordinary brake applied to the carrying wheels, a hand-brake applied to a drum with V grooves fixed on the pinion-axles, and an air-brake working also on the pinion-wheels through the cylinders, into which air is admitted, as in the Le Chatelier brake, and is compressed by the pistons, the peculiarity of the brake consisting of a valve in the outlet pipe, by the closing or

opening of which the pressure in the cylinders is varied. The following are the principal details and dimensions of the engines: four cylinders, $11\frac{1}{4}$ inches by 18 inches; two pinions, 2 feet $1\frac{9}{16}$ inch in diameter on pitch circle; four front carrying wheels, 3 feet 6 inches in diameter on fixed axles; two hind carrying wheels, 2 feet 6 inches, on bogie axle; rigid wheel-base, 8 feet 9 inches; total wheel-base, 16 feet 10 inches; tractive power per square inch of piston area, 178·6 lbs.; working boiler-pressure, 150 lbs. per square inch; weight in working order, 40 tons.

In working the traffic the engine is always placed at the down-hill end of the train, and thus pushes the load up the incline. One engine takes up four wagons weighing about 7 tons, and carrying about 10 tons each; the engine weighs 40 tons, the gross load of the train being thus about 108 tons. The gradient of the incline is 8 per cent. for a distance of 7,700 feet, and from $3\frac{1}{2}$ to $4\frac{3}{4}$ per cent. for the remaining length of 4,000 feet, the total length of the incline being about $2\frac{1}{4}$ miles. The minimum radius of curvature, 500 feet, occurs on the steepest part of the gradient.

All the stock is furnished with the Heberlein brake, and of course all brakes are put on when descending the incline; but even without this precaution the train would be completely under the control of the engine-brakes. The air-brake alone, without the other two, is capable of holding back any train which the engine could have taken up, and the hand-brakes can do the same without any assistance from the air-brake. The working of the incline is in short perfectly safe, the trains being as completely under the driver's control as on any other part of the line.

The only structures of any importance on the incline are four viaducts. The design of these gave some difficulty, not only on account of the steepness of the gradient, but also because the several parts of the viaducts had to be kept of small size, so that they might be conveyed up the narrow gorge in which the line is located. These requirements were completely fulfilled by Messrs. Livesey's designs (Plate 5), the viaducts proving very rigid under the passage of the engines, while the erection was easily effected. The time occupied, in conveying the ironwork for the four viaducts from the entrance of the gorge to the several sites and in erecting it, was two months.

The Author's object, in giving the foregoing account of this railway, is not to argue that the introduction of a gradient so steep as 1 in $12\frac{1}{2}$ was right in this particular case, this being a matter of only local interest; but to draw attention to the advantages, not in his opinion adequately recognized by engineers, of the system

of using steep inclines instead of long gradients. In the case of the Puerto Cabello Railway, the incline led to no saving of distance, nor did it reduce the gradients on other parts of the line, and the cost of locomotive working was therefore not much lessened; but in the great majority of cases where an incline can advantageously be used, it saves a long development of line and improves the other gradients with a consequent economy not only in first cost and in the maintenance of way and works, but also in the locomotive department.

It being once granted that a steep incline is the best method of overcoming the ascent which any particular line may have to surmount, the engineer has still to consider what mechanical appliances are best adapted to the particular case he has to consider. When the Author found that the Trincheras gorge, although rough and with very steep side slopes, was unusually straight, his impression was that the time-honoured system of rope-traction would prove to be the best. He found, however, that the local authorities would not approve of the system, and that if pressed it would lose the support of General de Castro, the only professional adviser of the Government who did not consider any incline to be more than a wild and unpractical scheme. The Author did not, therefore, prepare any plans or estimates for rope-traction, but recommended the Government to specify the Fell system as that to be adopted; and this accordingly was done. When, however, the Company was formed for constructing the line, their engineers, as has been already said, decided to use the Abt system of rack. In the Author's opinion the change was an improvement, experience of both systems having now convinced him that the improved rack is better than the Fell centre-rail where the curves are moderately good, more especially where the circumstances are such that engines independent of ordinary adhesion can be used, and where, therefore, the complication of coupled pinions can be got rid of. On the Trincheras incline, with curves of not less than 500 feet radius, the pinions work with practical accuracy into the rack; but, obviously, the imperfections of the system become more pronounced with the lessening of the radius of curvature. The mechanical drawbacks of the two systems may be thus summarised: in the Fell system there is increased journal friction, due to the pressure used in keeping the gripping-wheels in adhesion with the centre-rail; in the rack there is more or less friction, due to the imperfect adaptation of the pinion to the rack. The one is independent of the curvature of the road, while the other increases rapidly with it;

and there is, therefore, some radius of curve at which the two systems would be equally favourable, an increase of the radius tending to give the superiority to the rack, while a decrease would tend to give it the centre-rail. Experience, which is not yet attainable, can alone decide what is this limiting radius; but, in the Author's opinion, it is certainly less than 500 feet, the radius of the Trincheras curves, and may probably be less than 300 feet.

The Trincheras incline was opened for public traffic in March 1888, and has been working ever since without accident or difficulty.

Mr. William Archibald Smith, Assoc. M. Inst. C.E., was the Resident Engineer, and the Author superintended the construction for the Contractors.

The Paper is accompanied by several drawings, from which Plates 4 and 5 and the Figs. in the text have been prepared.

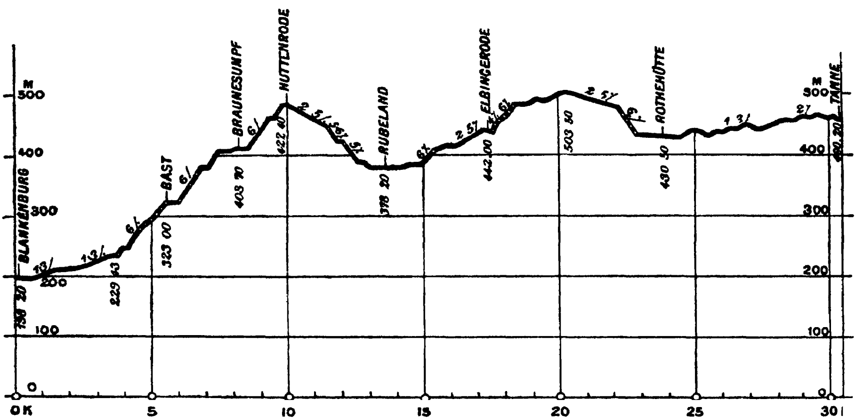
(*Paper No. 2379.*)

"Cost of Working the Hartz Mountain Railway."

By Robert Wilson, M. Inst. C.E.

With the view of substituting an incline for a summit tunnel on the New Zealand Midland Railway, the Author has investigated the cost of working the Hartz Mountain line, which connects the town of Blankenburg with Tanne, the present terminus in the mountain district. The special feature of the line is, that it is

Fig. 4



Longitudinal Section of the Blankenburg Hartz Railway

Scale Longitudinal $\frac{1}{300,000}$, Vertical $\frac{1}{12,000}$.

worked by locomotives constructed upon the Abt system of a combined adhesion- and rack-rail motive power. On the heavy gradients the trains are hauled by the combined powers, the pinion-and-rack not being used upon normal adhesion-grades; and the rack between the rails is only laid upon the grades necessitating its use; the pinions on the engines run in and out of gear with these racks, through the medium of a movable length at each end of the sections, fitted with this auxiliary.

Particulars and data, relative to the cost of working, may prove of some interest, more especially as, during the past few years, the subject of steep-incline lines, worked by other means than the ordinary adhesion locomotive, has been prominently before the engineering world.

Leading Features of the Hartz Railway (Fig. 4).

Total length, Blankenburg to Tanne	30·5 kilometres	= 18·95 miles.
Aggregate rise „ „	455·7 metres	= 1,495·10 feet
„ „ Tanne to Blankenburg	193·7 „	= 635·50 „
„ „ round trip	649·4 „	= 2,130·60 „ .
Average service weight of locomotives	52 tons	= 51·2 English tons
Standard weight of train	120 „	= 118·1 „ „
Average weight of train in 1887	97 „	= 95·5 „ „
Gauge	1,435 millimetres	= 4 feet 8½ inches.

Adhesive Sections.

Total length	22·936 kilometres	= 14·25 miles.
Maximum of gradient	2·5 per cent	= 1 in 40
Shortest radius of curvature	180 metres	= 590·6 feet.

Rack Sections

Total length	7 564 kilometres	= 4·70 miles
Maximum gradient	6 per cent	= 1 in 16 67
Shortest radius of curvature	250 metres	= 820·2 feet.

Traffic.

1886	Number of passengers	39,300
„	Weight of goods	81,100 tons = 79,819 English tons.
„	Total train mileage	59,653 kilometres = 37,067 miles.
1887	Number of passengers	53,500.
„	Weight of goods	120,000 tons = 118,105 English tons.
„	Total train mileage	94,802 kilometres = 58,908 miles.

Working Expenses, 1887.

	Marks	£	s.	d.	Per cent.
Salaries	40,742	= 1,997	3	2	= 24·09
Wages	47,182	= 2,312	16	10	= 28·00
General expenses, heating, lighting, &c	12,414	= 608	10	7	= 7·30
Maintenance of permanent way	18,417	= 902	15	11	= 10·90
Fuel, water, lubricants, &c	30,940	= 1,516	13	4	= 18 21
Repairs, locomotives and wagons	12,417	= 608	13	6	= 7·50
Rent of wagons of other railways	6,991	= 342	13	11	= 4·00
Total	169,103	= 8,289	7	3	= 100·00

These figures show the cost of working to be—

Per train-kilometre	1·78 mark	= 1s. 8·9d
„ „ mile	2·87 „	= 2s 9·8d

The working expenses of the railways in Germany and Austria-Hungary, taken from the latest statistics obtainable (1885), are as follow :—

The average for the railways in Germany is :—

Per train-kilometre	2·06 marks	= 2s 0·8d.
„ „ mile	3·82 „	= 3s. 8·7d.

The average for the railways in Austria-Hungary is :—

Per train-kilometre	2·36 marks	= 2s 3 2d
„ „ mile	3·60 „	= 3s 6 0d

The comparative cost of working is in favour of the Hartz line.

Expenses of Transportation and Motive Power, 1887.

	Marks.		£	s	d.
Salaries and wages	19,213	=	941	16	3·0
Fuel, water, lubricant, &c. . . .	30,940	=	1,516	13	4 0
Repairs to locomotives and wagons .	12,417	=	608	13	6·0
Total	62,570	=	3,067	3	1·0
Being per train-kilometre . . .	0·66	=		0	7·8
„ „ „ mile	1·06	=		1	0·5

From the statistics of 1885, before referred to, the following corresponding figures have been obtained for transportation and motive power, being the average on the German railways :—

	Mark.		d
Per train-kilometre	0·53	=	6 21
or „ mile	0·85	=	10·10
In Austria-Hungary per train-kilometre . .	0 67	=	7·90
„ „ „ „ mile . . .	1·08	=	12·70

It is misleading to make a comparison of the cost of motive power between the Hartz Railway, which is a succession of steep gradients, and two large systems of railway where abnormal grades are the exception and not the rule. A more equitable comparison is obtained by examining the expenses of transportation and motive power upon the Semmering Railway, the mountain section of the Austrian Southern Railway. The following data have been obtained from notes published by Mr. Gottschalk.

The leading characteristics of this line are :—

Total length, Payerbach to Gloggnitz	41·7 kilometres	=	25 9 miles
Aggregate rise	459 metres	=	1,505·9 feet
„ „ Murzzuschlag to Gloggnitz . .	218 „	=	715 3 „
„ „ Round trip . .	677 „	=	2,221 2 „
Maximum gradient	2·5 per cent.	=	1 in 40
Average weight of trains in 1887 .	131·8 tons	=	129·7 English tons.
Total train-mileage	565,858 kilometres	=	351,614 miles.

The expenses of transportation and motive power for 1887 were—

Per train-kilometre	0·89 mark	= 10·5d.
Per train-mile	1·43 „	= 16·9d.

These figures seem to prove that the introduction of the rack sections with steep gradients, on the Hartz Railway, does not increase the cost of working beyond that of a line with much easier gradients worked by adhesion-engines; instead of an increased cost, the figures show a substantial decrease.

Unfortunately, the data obtained relative to the cost of working on the Semmering Railway do not show the cost per train-mile in detail, so it is impossible to compare the relative cost of working the two lines except in the aggregate; and if it were possible, it would probably be misleading.

The fallacy of comparing two different systems of traction, upon two lines of railway by the usual standard of cost per train-mile, is, no doubt, apparent to all. The train-mile, being merely a standard of convenience, leaves entirely out of consideration the weight of trains, and the height to which they are lifted; so any comparison as to economy of working individual lines, made by the standard of cost of working per train-mile, would be much like comparing the efficiency of two pumping-engines without knowing the depth from which the water is lifted in each instance; unless the railway systems, so compared, are of such magnitude as would eliminate by average, without sensible error, the differences of grades, curves, &c., upon each.

A suggestion has been made to the Author, by Mr. Rinecker, to compare the Hartz and Semmering Railways by a standard of cost of work performed in overcoming friction and gravity. Such a standard appears applicable in the present instance. Taking the work performed as the product of the weight and height, the lines being practically continuous undulations, distances may be treated as a factor of friction, and eliminated from the calculation, because the expenses corresponding to friction are included in the expenses of lifting the weight. On this basis the following comparison has been made:—

	Hartz.	Semmering
From the foregoing data[1] the entire length of round trip is	37 9 miles	51 8 miles
Aggregate rise	2,130 6 feet	2,221 2 feet
Average train load exclusive of locomotive	95·5 tons	129 7 tons
Work performed per round trip	203,472 foot-tons	288,090 foot-tons
Expenses for transportation and motive power per train-mile	1*s* 0 5*d*	1*s*. 4·9*d*
Do. per round trip	£1 19*s* 5·7*d*	£3 12*s* 11·4*d*.
Per 1,000 foot-tons	2 3*d*	3·0*d*

[1] The weight of the locomotive is not included in the calculated weight lifted, but the expenses for lifting the same are included in the aggregate expenses, because lifting the locomotive is part of the cost of raising the train's weight.

Therefore the cost of lifting 1,000 tons of train weight to a height of 1 foot at the Hartz is only 76·6 per cent. of the cost at the Semmering. The difference would be still more in favour of the Hartz if the traffic were anything like the amount that it is on the Semmering line. The difference in the cost of raising 1,000 tons 1 foot on the two lines may, in a great measure, be accounted for by: (*a*) The pure adhesion locomotives being heavier than the Abt combination engines. (*b*) The number of engines employed on the Semmering line being greater, in comparison to the work performed, due possibly to the fact that at the Hartz the heaviest traffic is down the greatest percentage of steep grades. (*c*) The steaming capacity of the Abt engines is better than that of the adhesion engines at low speeds, due to the exhaust of four cylinders instead of only two. (*d*) The superior quality of coal used on the Hartz line, being patent fuel in bricks. (*e*) The combination-engine developes a definite power through the rack-and-pinion, and cannot slip in any state of the atmosphere, which is not the case with the adhesion engines.

Consumption of Fuel.

The consumption of fuel in a locomotive is mainly governed by the gradients and special details of construction, provided other conditions are equal. The following details give the consumption of fuel on the Hartz line for 1887.—

		Kilograms.		Lbs
Amount of coal per train-kilometre . . .	=	13·72		
,, ,, ,, mile	=			48·680
On round trip of (61 kilometres = 37·9 miles)	=	837·000	=	1,845·000
per 1,000 foot-tons train weight . . .				9·070
Per English indicated HP				3·898

From statistics published in Germany, relative to the railways in that country, the average consumption of fuel in the locomotive-engines, per indicated HP., is 5·253 lbs.

It appears to the Author that one of the great advantages obtained by the system of combined adhesion-rack on the Hartz, is that it enables the same engine to take the load over the entire line, notwithstanding the exceptional grades on various sections. No doubt, if a line is so located as to necessitate the use of an assistant bank-engine at one or several points, great increase of cost of working must ensue, unless the traffic is such as will keep the bank-engine in constant work. Take, for example, the cost of working the Rimutaka Incline by the Fell system, which is 3*s.* 8*d.* per train-

mile, against 1*s.* 0·5*d.* with the rack system on the Hartz line.[1] The Fell engines on the former line work only the short incline of 2¼ miles, and have often to stand in steam waiting for a train, consequently cannot make credit mileage as in the latter instance; the difference of cost is doubtless mainly due to this cause, together with the extra cost of fuel and labour in New Zealand. Probably a saving in cost of working per train-mile would be shown if the Fell engines took the load a certain distance beyond the incline to meet the next train, instead of waiting at the foot and the head; but at present the weight of the Fell engines precludes them from running over any but the special section of rails laid on the incline.

No doubt it is a generally accepted fact, that an efficient system of motive power for steep gradients opens up a vista of great future possibilities in railway construction through mountainous country. The advantage of a good incline system may be summed up by a quotation from a work by the well-known American Engineer, Mr. A. M. Wellington (now M. Inst. C.E.):—[2]

"Attempting to get a line of a low, uniform gradient through a country of any difficulty whatever, is very apt to be enormously expensive, and to be possible at all only by frequent undulations, considerable detours, and much higher gradients over most of the line than there is any necessity for using. This results from the fact that it sets at defiance one of the broadest and most nearly universal laws of physical geography—to which there are few and rare exceptions on the whole face of the globe—that long stretches of easy plains or gently sloping valleys penetrate at intervals to and into the very heart of even the roughest regions, leaving short sections only over which high gradients are unavoidable. By following these easy routes as long as we can we accomplish over most of our line three desirable ends at once:—1. We get the cheapest line; 2. We get the lowest through grades; and 3. More than all else, we concentrate the resistances into the remaining more difficult section, so that the motive-power on it can be accurately adapted to the work required, and kept fully at work over the distance where it is used, thus making it almost a matter of indifference what rate of ascent we adopt on our more difficult sections—a fact which powerfully tends to still further reduce the cost of construction over those more difficult sections."

The Author takes this opportunity of thanking Director Schneider, of the Hartz Railway, for the assistance and courtesy received by him while paying visits to the line, and feels sure that the same consideration will be extended to any member of the Institution desirous of investigating the Abt system of incline.

The Paper is accompanied by a diagram from which the Fig. in the text has been engraved.

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1 New Zealand Public Works Statement, 1888. Return No. 23.

2 "The Economic Theory of the Location of Railways," p. 586. New York, 1887.

(*Paper No. 2357.*)

"Further Information on the Working of the Fell System of Traction on the Rimutaka Incline, New Zealand."

By Joseph Prime Maxwell, M. Inst. C.E.

An account was given by the Author, in 1880, of the working of the Rimutaka incline, then but recently opened.[1] It is thought that some additional data, relating to the most recent result of working the Fell system may be of interest, especially as the incline, which is on a gradient of 1 in 15, has many 5-chain curves which are worked with great facility on the Fell system.

The traffic over the incline both ways for the year ending the 31st of March, 1888, was equal to 50,000 tons of net paying load, the passenger tonnage being calculated proportionately to the non-paying load carried, as compared with goods tonnage. The cost of locomotive power for this service was equal to 4*d.* per ton of net paying load per mile. While this may seem a high rate, the cost should be compared with such services in other countries only after a careful comparison of the rates of wages. Labourers on the New Zealand Government Railways are paid 6*s.* 6*d.*; gangers, 8*s.*; mechanics and smiths, 9*s.* to 10*s.* 6*d.* per day of eight hours; drivers, from 10*s.* to 13*s.*, and firemen, 7*s.* 6*d.* to 9*s.* These rates, in some instances, are nearly double those in the United States, and still more in excess of European rates. Coal costs 17*s.* 6*d.* a ton. It has the following constituents:—fixed carbon, 62·87 per cent.; hydrocarbon, 31·64; water, 1·66; and ash, 3·83 per cent.

Since the incline was opened, many improvements have been made in the details of the original Fell engines. They have been introduced in two extra engines imported, and indicate the changes and improvements which experience in working has proved to be desirable and economical.

The gripping-wheels are turned to the profile of the centre-rails. Sand between the rail and gripping-wheels is not used, the wheels as now turned giving ample adhesion. The vertical motion of the engine on the springs being slight, the grooved gripping-wheels are not materially affected. Spherical crank-pins have been substituted

[1] Minutes of Proceedings Inst. C.E., vol. lxiii. p. 50.

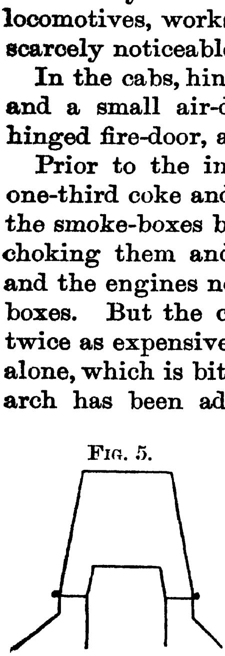
for the original straight pins, to allow for the gripping-wheels working out of the horizontal when turned smaller, or when drawn back from the rail. As the centre-engines are only required to run uphill, the original valve-gear has been removed, and a simple one substituted. The lead on the valves of the centre-engines, which caused a heavy knock on the geared-wheels, has been much reduced, and geared-wheels of cast-iron are working satisfactorily.

The Joy valve-gear, fitted to the outside engines on the new locomotives, works well; after twelve months' work the wear was scarcely noticeable.

In the cabs, hinged doors have been substituted for sliding doors, and a small air-deflecting door has been inserted in the large hinged fire-door, all firing being done through the former.

Prior to the introduction of arches in the firebox, the fuel was one-third coke and two-thirds coal, much of which was drawn into the smoke-boxes by the blast in ascending the incline, sometimes choking them and stopping the train; these have been extended, and the engines now run four trips without emptying the smoke-boxes. But the coke was destructive to the copper fireboxes and twice as expensive as coal; and to admit of the use of native coal alone, which is bituminous, very friable and rich in gas, the firebrick arch has been adopted, with firebars having air-spaces between of $\frac{3}{16}$ inch, and an improved blast-pipe (Fig. 5). To reduce the temperature in the cab, which had been excessive in the tunnels, fresh air is introduced from below through air-pipes, and the firebox fronts have been lagged. By an alteration in the pattern of the cast-iron brake-shoes, as shown by the lowermost of Figs. 6, three times the wear is now got out of them.

FIG. 5.



BLAST-PIPE.

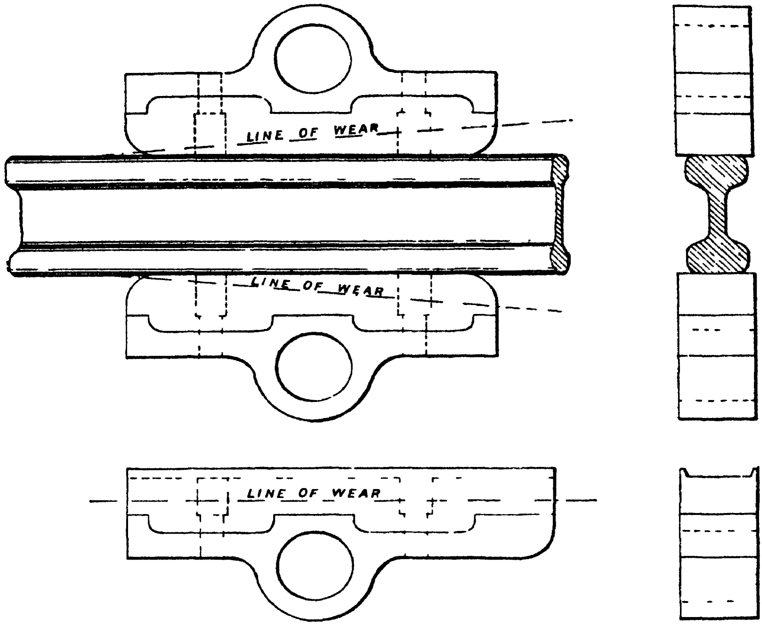
The water-tanks on the old engines have been increased at the expense of the coal-bunkers, so that there is an ample supply of water for watering the rails.

The inclined planes on the Widmark axle-boxes (Fig. 7) which were used for trailing axles, have been planed off, as it was found that they caused excessive friction on curves. Their removal permitted larger loads to be taken, and greatly lessened the wear of tires.

During the descent, the steam is used in the cylinders for lubrication, and jets of water are played on the centre-rail, just in advance of the brake, which cool the rail, and saturate the longitudinal sleepers, thus preserving them from taking fire, to

which they are liable in dry weather unless moistened. The brake also works more smoothly on a wet rail, and lasts three times as

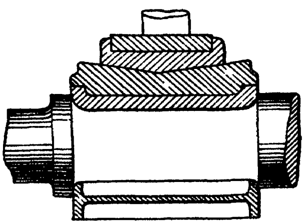
Figs. 6.



Centre-rail Brake-shoes.

long as on a dry rail; water is likewise used on the trailing-wheel tires both when ascending and descending, which wets the rails for the vehicles following. The wear of rails and tires is considerably lessened by the free use of water, and the train friction is reduced.

Fig. 7.



Radial Axle-box.

Additional sand-pipes have been fitted to the driving-wheels. All coupled wheels are supplied with sand; when two engines are working a train, if the rails are greasy the leading engine with sand works well, and without much slipping; but the second engine slips, unless the sand placed on the rails by the leading engine is washed off; this is effected by a jet of water from the second engine which places fresh sand on the rails.

The coupling-gear of the regulator handles has been removed,

and each regulator is worked separately. This was done to avoid stops; when one engine slipped, steam was, by the coupling-gear, shut off both in the outside and the centre-engine instead of the one only that was slipping.

All loads are now hauled; when two or three engines are used, each engine is so placed as to haul its own load. This works well, relieving the couplings of undue strain, and as a result broken couplings are rare. Forty-five minutes are allowed between the stations for ascending goods trains with a gross load of 65 tons exclusive of the weight of the engine; ample steam is generated for this duty, without forcing the fires. Loads of 70 tons per engine are often taken up, but this must be considered the maximum effort. Mixed ascending trains are allowed forty minutes, and a load of 60 tons. The distance is 3 miles. The centre-engine alone can take 40 tons up the incline, and the outside engine alone 30 tons.

Trains are worked with one, two, or three engines, according to the loads, without inconvenience, the engines being placed so as to divide the train to prevent overstraining the drawbars. The traffic is somewhat intermittent; a large portion being of live stock, having to be sent through without delay, at times entails three engines being in steam which have not nearly full work. A continuous traffic, which would allow of one or two engines being kept constantly at work, would be carried on very much more cheaply.

The low speed at which loads are taken up the incline, while it prevents wear and tear, and economizes fuel greatly, also lessens the risk of accident. Several years of working on the Fell system prove it to be quite successful, and well adapted for steep gradients with very sharp curves.

The capacity of such an incline for traffic will be limited by its length, among other things. An incline from 2 to 3 miles long, up which are conveyed loads of say 180 tons, with an allowance of an hour-and-a-half for the double trip, and with sufficient and convenient siding room at the foot and summit, is equal to the accommodation of an ascending traffic of 1,440 tons of gross load per day of twelve hours. A series of such short inclines, with suitable intervals to allow of crossing and watering, would evidently have the same capacity.

The Paper is accompanied by three sheets of tracings, which show the changes which have been effected since the line was opened, and from which the Figs. in the text have been prepared.

[APPENDIX.

APPENDIX.

PARTICULARS of WORKING for the YEAR ENDING 31st MARCH, 1888.

Train-mileage		10,859
Engine „		15,020
Coal, per mile	lbs.	110·73
Oil, per 100 miles	quarts	3·98
Tallow „	lbs.	0·95
Waste „	lbs.	4·64
Cost per engine-mile, *d.*—Repairs		19·38
„ „ Stores		0·55
„ „ Fuel		10·45
„ „ Wages		13·12
Total cost per engine-mile, *d.*		43·50
Cost of coal, per ton		17*s.* 6*d.*

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Discussion.

Mr. ROBERT WILSON considered the Paper by Mr. Carruthers very interesting as showing the differences of location of two lines, one upon a more or less uniform gradient, and the other on low levels up to a certain point, rising with sharp gradients to the summit. It was pointed out that there was a considerable saving in engine-mileage, that the speed was increased and also the carrying capacity. At first it was rather difficult to realize that such a thing was possible; and with a view of trying to make it more clear, he had taken the hypothetical case of an engine working for 100 miles over four lines at different gradients. The result of putting in an incline worked by specially designed machinery, such as the Abt or Fell engines, would be to double the load on 1 in 12½, slightly to increase the efficiency over the whole in 100 miles, and materially to reduce the train-mileage, namely to 167·5. There would be a saving of 73·35 miles on the working without special arrangements on the incline, and a saving of 18½ miles on the continuous-gradient route. It might be said that those were theoretical conditions under which a perfect incline would be obtained. Of course, as the approach-gradients became broken, or more severe, the effect would be diminished in proportion. That seemed to point to a very important consideration when locating such a line, namely, to keep the approach-gradients as low as possible until the point was reached where the final rise had to be made. Mr. Maxwell had referred to limiting the capacity of an incline. It appeared to Mr. Wilson that limiting the capacity of an incline, worked by the Fell or the Abt system, was merely a question of rolling-stock, because it was possible to have passing places on the incline, and when the traffic was beyond the capacity of such passing places to have a double road. Of course, with a rope-incline there was distinctly a limit of capacity. The great point in a line laid out as described was, no doubt, the first saving in cost of construction. He had known a somewhat similar case where, in the first instance, a section of line was surveyed with a more or less uniform gradient throughout, and estimates were made for the line carried along the lower flats as far as possible. The required rise was obtained by an incline, and the estimated cost was much in favour of the incline line. In this case the most important saving was effected by substituting the incline for the long summit tunnel, and avoiding a Mr. Wilson.

line of 15 miles, with a gradient of 1 in 50, through a country where the conditions were unfavourable to maintenance, having a rainfall amounting to 105 inches in a year, in conjunction with rocks of clay-slates of the Jurassic period. The hill-sides in places formed great shingle slides; maintenance on such ground would be exceedingly heavy owing to the slips, which it would be impossible to avoid without exceedingly heavy expenditure. He had investigated as far as possible the cost of working the Hartz line, the particulars of which were given in his Paper. His experience was very satisfactory. He had found that when the engines were entering the rack sections they did so without difficulty, without any blow or any indication that they were entering the tongue; they seemed to go over the tongue without trouble at 5 or 6 miles an hour. Upon the curves he found that there was a slight wear, but that was only the bedding of the pinion-teeth on the rack-teeth; the former being slightly at an angle, they, of course, bore heavily on the inside points of the rack-teeth; after the bearing was formed there appeared to be little or no further wear. Mr. Carruthers had stated that he considered the Fell system to be the superior with small curves, and that it would probably be more suitable for sharp curves than the Abt system; but Mr. Wilson questioned if there would be the advantage claimed. He thought the limit of curvature on the Abt system would be found to be the clearance in the tooth of the pinion with the tooth of the rack, and that it would possibly be a radius far below that mentioned in the Paper. The compression-brakes with which the engines on the Hartz line were fitted worked most effectively, giving the driver perfect control of the train, so complete that the trains could be stopped on an incline of 1 in 16 without difficulty. In bringing a heavy train-load down the long incline there were three brakes on the train besides that on the engine. He had recently received some further information from the Directors of the Hartz Railway for 1888, from which it appeared that the working in the year was satisfactory compared with the working of 1887.

Traffic on Hartz Line, 1888.

Number of passengers . .	58,550	Increase on 1887	.	5,050
Weight of goods	146,250 tons	,, ,,	.	26,250 tons
Total train-mileage . . .	57,256	Decrease ,,	.	1,652
Average weight of train run	105 tons	Increase ,,	.	8 tons
Maximum ,, ,, ,,	135 ,,	,, ,,	.	15 ,,

Maximum load consisted of nine loaded wagons, gross load of 15 tons each; three were fitted with friction brakes.

Mr.

Working Expenses, 1888.

	£	s.	d.
Salaries / Wages	4,372	10	0
General expenses	6,665	15	10
Maintenance	728	15	0
Fuel	1,506	1	8
Repairs (engine and wagons)	874	6	10
Hire of wagons	437	3	5
	£8,584	12	9
Cost per train-mile		2	10·9
Coal	51·2 lbs.		
Lubrication	2·2 ,,		

The increase of coal per train-mile was due to the trains having been on the average heavier.

Cost of Transportation.

	£	s.	d.	Per cent.
Wages	815	13	8	27·8
Fuel	1,179	5	3	40·2
Stores	244	7	8	8·3
Water	17	1	3	0·6
Repairs (locomotive)	677	12	6	23·1
	£2,934	0	4	100 per cent.

Cost per train-mile . . . . 1·019*s.*

Mr. Maxwell had mentioned the improvements in the new Fell engine sent out from England. As one of the government engineers Mr. Wilson had supervised building the engines mentioned. The coupling-rods and the connecting-rods of the inside engines were made with a ball-and-socket joint, with an increased heating surface. The cab was so constructed that it could be entirely closed in; because on the sharp incline in the tunnels the foul air was very objectionable. When he went over the line there was an engine at the tail-end of the train, and he found very great inconvenience from the bad air, the sulphurous acid being very strong and disagreeable. Indeed, it was so bad that it had been expedient to fit pipes, one on each side of the foot-plate, 3 inches in diameter, and to carry them down to about 2 feet 6 inches from the road, and 3 feet 6 inches up in the cab. By means of those pipes the men on the engine were able to get fresh air, and he was himself thankful to monoplise one of them while going through the tunnels.

Captain C. Fairholme.

Captain C. Fairholme, R.N., said he was not qualified to speak on the technical part of the question, but as representing Messrs. Rinecker, Abt and Co., he desired to express his regret that no

Captain C. Fairholme. member of that firm was able to be present, and to submit some information supplied to him by them on the subject under discussion. Mr. Carruthers had referred to there being only one type of locomotive for the Abt system, and Captain Fairholme had also been asked to explain that there were three, namely, the combination type for adhesion and rack combined, the coupled type, where the pinion was coupled to the driving-wheel (as used on the Oertelsbruch slate-quarry railway), and the pure rack type, of which the Puerto Cabello and Valencia engine was an example. The Abt system was already in use on the following railways:—The Hartz Mountain line, gradient 1 in 16·67; Oertelsbruch Lehesten, 1 in 12½; Oertelsbruch quarry line (2 feet 3⅜ inches gauge), 1 in 7·3; Puerto Cabello and Valencia, 1 in 12½. In Austria the Eisenerz-Vordernberg, and in Bosnia the Mostar Serajevo, lines, were now to be built, and the system was also in use on the following rope-railways, as a special means of security for the descent:—Lugano station, gradient 1 in 4; Kehrsiten-Bürgenstock, 1 in 1·73; Limmatquai-Polytechnicum, 1 in 3·84; Chiaia-Vomero, Naples, 1 in 3·35, and Montesanto-Vomero, Naples, 1 in 4·31. In 1887 the Indian Government ordered, for experimental purposes, 7 miles of triple-rack rails with the necessary switches and entrance tongues, and two locomotives of 5 feet 6 inches gauge. The locomotives, with 50 tons average service weight, were each able, by means of the rack, to haul 135 tons up 1 in 20, and round curves of 600 feet radius, at 7 miles an hour, the same engine being able to move the same load up 1 in 40 at 11 miles an hour without the rack. The first trials having been made on a gradient of only 1 in 25, the train load was fixed at 170 tons, and 1 in 50 as the corresponding gradient without the rack. The experimental line was only 1 mile long, and at the trials in March and April, 1888, the engine-drivers and firemen had not got accustomed to their engine, and consequently the Indian authorities wrote:—"No practical conclusions can be drawn from the performance of new engines on a short experimental line. Further experiments are contemplated with the Abt engines, and it is proposed to conduct these at suitable speeds, after the 5 feet 6 inches gauge line has been laid through from Hirokh to the Khotal." The experiment having been conducted on the Bolan State Railway, a report had been circulated that the Abt system was "in service upon the Bolan Railway"; but this was not correct, as the Indian Government had not arrived at any decision on the matter. In order to work trains on steep gradients by pure adhesion with ordinary locomotives, the weight upon the driving-

wheels should be as great as possible; but as this weight was limited by the strength of the permanent way, it had been necessary to increase the number of coupled-axles. It was found, however, that, owing to the unequal wear of the tires, and their rolling through curves upon varying diameters, considerable losses of power by friction, &c., ensued; the coupling of more than three axles had consequently, in most cases, been abandoned, and the system introduced of having two distinct sets, of three coupled-axles each, under either one common boiler, or twin boilers, or else as twin engines. The Fairlie locomotive might be taken as perhaps the best type of such a principle. The Abt combination locomotive had, in a similar manner, two sets of machinery, but simplified, as compared with the Fairlie, by having only one boiler and one firebox, and by keeping one set of its machinery at rest when not required. Upon easy gradients, where one set of machinery should suffice, the other set, in the case of the Fairlie engine, must also be in motion—whether steam was admitted or not—thus producing wear-and-tear and a loss of power, to say nothing of the whole weight of the second half of the engine having to be carried uselessly. With the Abt system, on the contrary, an adhesion engine was taken, just sufficiently heavy for the pure adhesion sections of the line, and the pinion machinery was then added, without materially increasing the weight. The speed of such an engine upon the steeper gradients would, of course, be less, because a greater portion of the steam would be utilized as motive power in proportion to the increase in steepness of the gradient. This loss of speed was, however, of less consequence than would appear, and, indeed, owing to the smaller number of trains required to do the same amount of work, there was practically a gain in time on the average in working the traffic, the principal advantage of the system being the proportionately smaller aggregate dead-weight moved over the incline. That this was the case would be obvious from the following considerations: A pure adhesion engine could move over a given incline, owing to its tractive force and adhesion weight, a certain train-load at a certain velocity. Let the train-load be assumed to be about the same as the weight of the engine (which would be the case, according to the coefficient of adhesion, with gradients of from 1 in 25 to 1 in 20), and assume the weight of the engine to be 50 tons; its tractive force would thus be equal to 100 tons. The addition of the pinion machinery to this adhesion engine would not materially increase its weight, but it would double its tractive force. This meant that 200 tons could be moved up the very same incline by the same engine thus

Captain C. Scholme. altered, and that the train-load could be increased from 50 to nearly 150 tons. To move 150 tons of train-load, the pure adhesion locomotive would, however, have to make the trip three times, or, in other words, the dead-load would be three times as much as with the combined engine. It was true that this treble load was only moved by the combined engine at half the speed at which the pure adhesion engine would move each of its three single ones; but the total load was anyhow moved quicker to the top of the incline. Fewer locomotives were consequently required, with fewer drivers and firemen, and smaller engine sheds, besides the other advantages, in fuel, &c., of working a smaller dead-load. These remarks only hold good, of course, to their full extent, for the comparison between the Abt and the ordinary engine; because, in the case of any duplex engine, whether Fell or Fairlie, the difference would not be so large. To return to the comparison with the Fairlie system; let it be supposed that a heavy engine be taken, and that one of its sets of six adhesion wheels be left coupled, the other set being converted into three uncoupled axles, the Abt coupled pinions being then added. There was now at one end a rack-engine, at the other end an adhesion engine, nothing else being altered except that the total weight had been perhaps slightly increased, the tractive force and velocity remaining the same. A great improvement had, however, been effected, since, on the easy gradients, where the adhesion set was sufficient by itself, the losses of power, due to the friction of the other set, had been done away with; whereas, on the steeper grades, where the driving force of the pinions was added, less frictional loss resulted than with a second set of six-coupled adhesion wheels. All slipping of wheels was also done away with, and variations of adhesion, due to climatic changes, did not come into account, whilst the gradients could even, if necessary, be increased; besides which, perfect safety in descending the inclines was guaranteed by the rack. This, however, was not all, as the construction of the engine might be still further improved. The rack-rail upon which the pinions worked being a central one, space was gained for the two sets of machinery; whilst, instead of two fireboxes, two boilers and two chimneys, only one of each was required, the aggregate heating surface being the same as before, but the total weight being diminished. No flexible steam-pipes were necessary, and the front end of the boiler could be fixed to the frame, the rear end resting on slides, and being borne by the three uncoupled axles which had been gained by doing away with the second set of adhesion machinery. The improvement, however,

extended also to increasing the steaming quality in addition to simplifying the arrangement. As was well known, the steam-generating power of a locomotive increased with the speed, owing to the greater number of beats in the exhaust. The combination locomotive obtained by improving (as above described) on the original idea of the Fairlie engine, had still the same heating surface and speed, but had the exhaust of four cylinders beating jointly at very short intervals into one and the same chimney, and a far better draught must consequently be the result than with the former two separate sets. The experience of several years on the Hartz and Oertelsbruch railways had fully established the reality and value of this last improvement. The type here described of a six-coupled tank engine was only given as an instance, as of course the system could be equally well employed with any other type of engine. For the Abt system, tank engines were preferable for steep gradients, on account of their smaller weight; whilst the disadvantage of the varying weight for adhesion due to the weight of coal and water carried becoming less, was of scarcely any consequence with the rack. Captain Fairholme

Mr. J. W. Grover said that the gradient of $3\frac{1}{2}$ per cent. for the La Guaira line had been adopted entirely in consequence of the conformation of the country. The line from La Guaira to Carácas, which was the parent of all the lines in the country, was originally laid out in 1873, when he had made some of the surveys, and reported upon it, and his report was ultimately adopted. In the centre of the line there was a great pass called the Boqueron, which rendered this gradient inevitable. The pass had very steep, precipitous sides, and it was impossible to make a railway except with a succession of sharp curves going round the summit of the pass. It appeared from the Paper that the engines constructed for the Puerto Cabello and Valencia Railway, on the Abt system, were not to work by adhesion at all; but according to the views of the Engineer of the Hartz Mountain system, the Abt engine should be able to work through, whether there was a rack or not. Perhaps it would be explained why the engines were not made to work on the adhesion principle like those on the Hartz incline. The La Guaira and Carácas Railway had been most expensive to maintain, in consequence of its being constructed on the side of very steep hills. The soil on the side of the mountain would sometimes come down in the night, and trees would be found standing in the middle of the road. Any method which would enable an engineer to construct a line away from the side of such a slipping mountain would be desirable. Mr. Gr

Martineau. Mr. W. Martineau remarked that in studying the subject of the Papers, the members ought not to overlook what had been done in Brazil, a country where several large and important steep inclines had been constructed. There was first the incline, or rather a series of inclines, on the São Paulo Railway, constructed by Sir James Brunlees, but as a Paper had been read on the subject by Mr. D. M. Fox in 1870,[1] he need not further remark upon it, except to say that if the additional experience of twenty years' working had elicited any further information, the members would be glad to hear it. He might also refer to the Cantagallo line, the gauge of which was 3 feet 8 inches, and where the Fell system had been adopted for a distance of $8\frac{1}{4}$ miles; in fact the material and the engines had been brought there from the Mont Cenis Railway. The incline on which the Fell system was laid varied from 4 to 8 per cent., the total height attained being about 3,300 feet. But the Fell system did not seem to have met with the same success as on the Rimutaka line, in New Zealand. After the Fell system, which he believed was no longer working, the Fairlie engine had been tried. He himself inspected a Fairlie engine made by the Yorkshire Engine Company for the line some years ago. It did not seem to have afforded entire satisfaction, and he had been informed that the line was now being worked with American engines made at the Baldwin Locomotive Works. They had three pairs of wheels coupled, 3 feet 3 inches in diameter, 18-inch cylinders, and a stroke of 20 inches; the weight of the engines was about 40 tons, and they took another 40 tons up an incline of $8\frac{1}{2}$ per cent. It did not seem very economical for an engine to take only its own weight up an incline. The incline to which he wished specially to refer was on the Petropolis Railway. This was not a mere pleasure line like the Rigi, but was a regular means of communication. It gave communication between the City of Rio de Janeiro and Petropolis, which was the summer residence of a large portion of the population, and where the Emperor and Court then resided, so that the line carried a considerable amount of passenger and goods traffic. It was a rack-railway, the rack portion being $3\frac{3}{4}$ miles in length, and the incline was 15 per cent., or 1 in $6\frac{2}{3}$. It started from the terminus of a railway known as the Mauá Railway, originally constructed by Viscount Mauá, which claimed to be the oldest railway in South America; but he believed that honour belonged to the Lima Railway. Starting from the Bay of Rio de Janeiro, it went a distance of 10 miles over a level country to the

[1] Minutes of Proceedings Inst. C.E., vol. xxx p. 29.

foot of the hills. The remainder of the journey to Petropolis us to be performed by coaches over the road; but was now performed by the rack-railway, the same carriages being taken through. The train started from Port Mauá with these carriages, and went to the station at the foot of the hills. The engine then left the head of the train, passed through the points, and went to the tail of the train; it then pushed the two leading carriages on to the rack-railway; the rack-engine followed pushing these two carriages. Then two more carriages were pushed on to the rack, and a second rack-engine came behind them, and the remaining two were taken by a third rack-engine. There were three rack-engines, each pushing two carriages in procession. When they arrived at the level line at the top, the reverse operation took place. The carriages were detached from the rack-engines, and the train was made up again, and taken on with an ordinary engine to Petropolis. The total height gained on the incline was about 2,800 feet in a length of $3\frac{3}{4}$ miles. The gauge of the line was 1 metre; the weight of rail, 40 lbs. per yard; the weight of rack, 100 lbs. per yard; the sharpest curve, 491 feet radius; the sleepers were of native timber, 6 feet by 8 inches by 6 inches. The engines were of the Riggenbach type. The coal consumed per kilometre was 28·570 kilograms, equal to 100 lbs. per mile; coal consumed per ton per kilometre 0·085; the cost of the line, from the foot of the incline to Petropolis, had been about £140,000, which was equal to about £25,000 per mile. The total capital of the Company was about £350,000, which included the purchase of the Mauá Railway, steamers, &c. The profit was stated to be about £24,000 per annum, which was a very good return on the capital. If it were possible in that country to lay out a line that should develop the length necessary to attain that height with a gradient, say, of 1 in 40, instead of being $3\frac{3}{4}$ miles long, it would have to be $22\frac{1}{2}$ miles, and it would necessarily be a line of a much more expensive character. He had mentioned the Petropolis line in particular, on account of the great success that had attended its working, and the way in which heavy traffic of passengers and goods was regularly carried between Rio de Janeiro and Petropolis. There was one other incline in Brazil which might be worth mentioning: that on the rack-railway recently made up the Corcovado mountain, in the neighbourhood of Rio. It was purely a pleasure line; the steepest incline was 30 per cent., or 1 in $3\frac{1}{3}$, which he thought was about the steepest ever attempted.

Sir George B. Bruce, President, said, a letter had been received Sir G
from Mr. Livesey, in reference to a reason for adopting the Abt Bruce

Sir George Bruce. system referred to by Mr. Carruthers. "One reason," he said, "for adopting the Abt in preference to the Fell system was, that at times locusts abounded in Venezuela, and we felt assured that their presence on the rails would be fatal to any system relying solely on adhesive action." That reason had not been mentioned by Mr. Carruthers.

Mr. Woods. Mr. EDWARD WOODS, Past President, observed in the Appendix mention of a rack-railway and cog-wheel locomotive in 1811, so that the rack system was not quite new. The improvements, however, by Mr. Abt, and the invention by Mr. Fell, applied in the first instance on the Mont Cenis Railway, had been so effective that the old rack system was now out of date, although it was at one time suggested that it might be applicable to the working of the traffic of the Liverpool and Manchester Railway. Of the systems which had been brought before the notice of the members in the Papers just read, he thought the Abt system the most effective, although the Fell system had also worked well. The systems described appeared to him to be most applicable where the gradients exceeded 1 in 20, or 1 in 25. Railways with gradients not steeper than 1 in 25 were worked effectively simply by locomotive power. Some locomotives were specially designed for working such heavy gradients, but others were of the type in ordinary use. On the West Coast of South America, in Chili, there were many railways from the coast to the lower ranges of the Andes, with gradients of 1 in 20, 25, and 33, running, perhaps, for 20, 30, and 40 miles at a stretch, all worked by locomotive engines. No doubt on the western side of the Andes the climate was so dry that the disadvantages of slipping were not felt so much as they were on European railways. He had been afforded the opportunity, by Messrs. Beyer, Peacock and Co., of examining one of the engines made for a railway in Venezuela, and he was much pleased with its construction, and thought it admirably adapted to the work which it had been effectively doing. The combination system was, he thought, specially applicable to those cases in which the line, so to speak, undulated in the vertical sense, and where the steep gradients occurred during the course of the line, rather than being concentrated at the end. In the case described by Mr. Martineau, and in that mentioned in the first Paper read, he thought it was a prudent course to concentrate the gradient at one end, and to apply the simple rack system, not adopting the combination system. But where steep gradients intervened over different portions of the line, as he believed they did on the line opened last summer over the Brunig Pass, connecting

Lucerne with Brienz, the combination system was especially applicable. Mr. W

Mr. J. B. Fell wished to make a few remarks on Mr. Maxwell's Paper. It appeared that some new engines had been made subsequent to the original engines sent out to New Zealand several years ago; and that improvements had been introduced into them which had resulted in efficiency and economy in the working. The improvements consisting in grooving the centre-rail wheels so as to bite upon the rail, thus avoiding the use of sand, and getting additional adhesion, and the plan had been successful. He had thought of it before the Mont Cenis Railway was made, and he had discussed the question with Mr. Ramsbottom, who believed that the tendency would be to draw up the centre-rail, or throw too heavy a load upon the spring-plates of the engine; but that did not appear to be the case. So far as the engines had worked on the line in New Zealand, they had proved that the centre-rail system had been certainly a success to the extent of doing its work. The question was whether it was doing the work economically. Mr. Wilson had contended that the rack-and-pinion system was more economical and better adapted under some circumstances; and he had stated that whereas the cost per train-mile for locomotive power in New Zealand was 3*s.* 8*d.* it was only 1*s.* 0½*d.* on the Hartz Mountain line. But, as he had observed, the circumstances were totally different. In the first place the cost of labour was double in New Zealand what it was in Germany. Then again, on the Hartz line the engines ran through, and were worked by adhesion and also by the rack-and-pinion; whereas on the Rimutaka, the engines worked on the incline alone, and were therefore more than half their time under steam without doing work. He saw no reason why the engines, which were able to run on flat as well as on steep gradients, were not made to run on to the Wellington station and back. On the Mont Cenis, parts of the line were flat, and there were gradients of 1 in 12, but the same engine was run over the entire line. If that had been done in New Zealand, the cost per train-mile would have compared more favourably with the cost on the Hartz line. It appeared to him that the engines, though doing their work fairly satisfactorily in New Zealand, were not the best class of engines if they were only worked on the incline. It would be quite possible to work them with two cylinders instead of four, and then they would be more efficient, and the adhesion would be better, because when the carrying rails were slippery the centre-rail might be dry. On the Mont Cenis line two cylinders were first used, and they

Mr. Fell. were more powerful, getting up steam better, the exhaust being more regular; but there was the difficulty that the outside wheels were worked by rocking-shafts and by oblique connecting-rods; and, although the diameter of the inside and outside wheels was exactly the same, they did not travel at the same rate at the same time. For instance, each quarter of a revolution was made in less time by one set of wheels than by the other, and there was a scrub, which caused a great deal of friction, wear and tear, and sometimes breakages. The four-cylinder system was therefore reverted to on account of that difficulty; but this was simply a retrograde movement because, in the first experiments, the four-cylinder arrangement was used, and afterwards that of two cylinders had been adopted as an improvement, which, however, had not been quite satisfactory on account of the mechanical defect he had mentioned. In the designs prepared by the Italian Government for working over the pass of the Mont Genóvre, at an elevation of 6,000 feet above the sea—a much higher level than the Hartz Mountain railway—weigh-beams had been adopted in place of rocking-shafts for driving the carrying-wheels; and by this new arrangement the movements of the two sets of wheels would be coincident and mathematically correct. This class of engine would be best adapted for the Rimutaka incline, if the engines were required to work on the incline only. The present engines, it appeared to him, might work for any distance on either side of the incline, because the vertical wheels were of much larger diameter than the others. He had prepared drawings of the improvements which had been proposed to, and adopted by, the Italian Government for working over the inclines of the Mont Genóvre, of which there were two of 5 miles each, upon gradients of 1 in 15. It was expected that these engines would shortly be running over the mountain, and he hoped then to be allowed to bring before the Institution a report upon the working of the engines, and of the cost of locomotive power, which, if all the elements of cost were taken into account in both cases, he believed would be quite as favourable, and in some respects more favourable, than the results which had been obtained by the rack-and-pinion system. No doubt, in some respects, more could be done with the rack-and-pinion than with the centre-rail system, as it could be worked on gradients of 1 in 5, but the centre-rail system had the advantage of permitting the use of sharper curves. The principal element, however, in the cost of working mountain railways was the elevation to be overcome, and the cost of traction would be very much in proportion to that elevation. Mr. Wilson had stated that there was more axle-

friction (and there certainly was a little more) with the centre-rail system as compared with the rack-and-pinion; but, taking the pressure on the horizontal wheels at 40 tons, and the axle friction at 20 lbs. to the ton, the total resistance would only be $\frac{1}{30}$ of the tractive power of the engine. Upon the inclines of the Mont Genévre the engines would have a tractive force of about 10 tons, after allowing for the friction due to the axles of the horizontal wheels; but this being about $\frac{1}{30}$ part of the total resistances, all that could possibly be saved by the rack-and-pinion system would be a fraction of this thirtieth part, which was a matter of small consideration, the cost of traction being in fact almost in exact proportion to the vertical height to be overcome. He should be glad to be informed why the centre-rail engines in New Zealand had only been working on the incline, and not also upon the level portion of the line, as had been the case on the Mont Cenis Summit Railway, where out of a distance of 48 miles there had been about 20 miles of line with gradients of 1 in 12 to 1 in 15, all the rest being comparatively level.

Mr. Ernest E. Sawyer remarked that now that railways were being extended into parts of the world sparsely inhabited, and often very mountainous, it became more and more a question of importance how to deal with steep inclines. Mr. Carruthers had illustrated the advantage of steep inclines. Mr. Wilson had given the working of one of the best systems of getting over steep inclines, and Mr. Maxwell the result of about ten years' working of steep gradients. He had suggested to Mr. Maxwell that, having had the working of the only Fell railway that he knew of for the last ten years, he should give the Institution the benefit of what he had learned. In the first Paper, although Mr. Carruthers advocated a special system for going up a steep incline, the "key of the line" was not that incline at all, but was the section between Cambur and Trincheras. He thought a little more might have been said about that section. The steep incline was only $2\frac{1}{4}$ miles of about 1 in $12\frac{1}{2}$, whilst the part from Cambur to Trincheras was $6\frac{3}{4}$ miles of 1 in 29, which was sufficient to give ample advantage to the special system. If it had been 1 in 40 a second engine would have been able to take up the train entire without its being broken up; but in this case the engine could only take one-third of the train, so that it had to be broken up, or three engines would have to be put on. Mr. Mosse, who had had a great deal of experience in the Mauritius, where the gradients were continuous of 1 in 27, had expressed an opinion that no gradient for a long rise should exceed 1 in 40.

er. Having had the advantage of working a line for some time where there was an almost continuous rise of 1 in 40 for 8 miles, Mr. Sawyer quite agreed that that was as steep as any line ought to be worked by ordinary means. The trains on the Bolan Railway in India started from the plains with one engine up ruling gradients of 1 in 100; on coming to a grade of 1 in 40 a second engine was put on; and then, coming to grades of 1 in 22, a third engine was put on; the train being maintained intact all through. Every traffic manager knew this to be a matter of the utmost importance. In the same way, on the Canadian Pacific Railway, the Selkirks and the Gold ranges were surmounted by simply adding an engine to the train; on arriving at gradients of 1 in 40, one engine was added, and on reaching gradients of 1 in 22, a third. In that way the difficulty was overcome without any trouble, every train being kept intact. In the case described by Mr. Carruthers there was a special road and a special engine, and yet that was not the key to the line. There was only one suggestion that he could make why this was so, viz., that the curves on the line from Cambur to Trincheras were of 300 feet radius, whilst those on the piece from Trincheras to La Entrada were 500 feet. Was that the reason why the Abt system had not been employed on the Cambur and Trincheras section? Mr. Carruthers had fathered the Rimutaka incline; he was really the Author of it, and had very good reason to be proud of it. From what Mr. Sawyer had seen, it worked splendidly. Mr. Carruthers had said that he intended to use the Fell system in this case also, but as he was there on the part of the Contractors, he had to give way to the Company's Engineer. He should be glad to know whether, if he had had his own way, he would not, having adopted the Fell system, have started it at Cambur, and worked it all the way through to La Entrada? If he could have got the train with one special engine up to Trincheras, he had only to put on two engines to get the whole train to La Entrada, which, from a railway manager's point of view, was of the utmost importance. He had been told by Sir Guilford Molesworth that the Oertelsbruch Railway, built by Mr. Abt, had curves of 325 feet, and that one was contemplated with a curve of 197 feet. Any information as to those two lines would be very valuable to the Institution. Mr. Carruthers had stated that although the Trincheras gorge was very rough and steep, it was unusually straight, and his impression was that the time-honoured system of rope-traction would prove the best. Mr. Sawyer agreed in this, and held that rope-traction was one of the systems of overcoming steep gradients that engineers had somewhat neglected.

It used to be far more common than at present, and probably it Mr. Saw had given way before prejudice; but the development of traction by wire ropes had been so great in America with tramways, and so improved, that he thought very little more was required to make it exceedingly useful in connection with railways. At San Francisco a speed of 10 miles an hour was attained on gradients of 1 in 4½ with curves of 20 or 30 feet radius. The cables were over 5 miles long, and they worked even up to 10 miles economically. He was not able to ascertain exactly what weight they could haul, but he had seen cars with two hundred and fifty passengers following each other within sight on the same cable, and going at 10 miles an hour with far more safety than a London omnibus. There was an example in London of a cable tramway up Highgate Hill, but it was not at all like what might be seen in San Francisco. It had fared badly between the Vestry and the Board of Trade, and was now figuring in the Bankruptcy Court. It was a remarkable example of public prejudice. The charge for going down hill had been reduced to 1*d.*, the fare up hill being 2*d.*, but even at 1*d.* the people were afraid to go down hill, because they thought it was more dangerous than going up hill. The statement of Mr. Carruthers as to the gorge being straight, so that rope-traction would be applicable to it, was hardly worthy of attention, since it was now possible to go round curves of 20 or 30 feet radius with the greatest ease. The present system had been so developed that there could be no danger of breaking the rope. He was himself on a car going down a gradient of 1 in 4½ at the usual speed. Another car was coming up hill, and it stopped a little before the other came up to it, and some of the passengers got out. A high wind was blowing, and the hat of one of the passengers was blown off and fell on the tram-line on which he was. The man not seeing the other car ran on to the track for his hat, when the approaching car was only about four lengths from him. The grip-man instantly took off the grip and put on the double-brakes, one working the wheels and the other on to the rail. The car was stopped easily within a length of the man. Of course, the passengers were slightly heaped up at the lower end, but the man was safe. That was a good example of what could be done in stopping the cars at any moment. So long as the man was watchful there could not be an accident. The advantage of rope-traction over any system requiring a locomotive to go up an incline was self-evident. On the Hartz line there was a maximum train-load of 120 tons, the average load being 97 tons. The weight of the locomotive was 52 tons, or from 44 to 53 per cent. On

Sawyer. the Puerto Cabello line, on the piece from Cambur to Trincheras, the maximum load was 68 tons. Taking off 20 per cent. for the average load that would be 55 tons; the locomotive was 37½ tons on that portion, or from 58 to 68 per cent. of the load it took up. On the next piece, from Trincheras to La Entrada, there was a maximum load of 68 tons and an average load of 55 tons; the locomotive was 40 tons, the percentage of the locomotive to the train-load being from 57 to 74 per cent. On the Rimutaka incline the load was from 70 to 60 tons; and the weight of the locomotive was 39 tons, or from 55 to 65 per cent. So that in every case the weight of the engine was from 50 to 60 per cent. of the load of the train it took up. Of course, with any system of rope-traction, only the loaded cars, and nothing more, had to be drawn up. The next point to be considered was how the special arrangement, of whatever kind, compared with ordinary traction. Sir Juland Danvers had kindly placed at his disposal a report of some experiments made in 1887 on the Mexican Railway. It was a very important report, and it drew attention to the fact that the best ordinary locomotives were expected to go up a gradient of 1 in 25 with a load twice their own weight, and to ascend a grade of 1 in 13 and haul up their own weight, at 7 miles an hour. It was also stated that on the Cantagallo Railway in Brazil, the locomotives of the Baldwin Locomotive Company in Philadelphia, of 40 tons, drew a load of 38 tons at 8 miles an hour up a gradient of 1 in 12 with curves of 83 feet radius. Those locomotives had generally eight wheels coupled, the four inner wheels having no flanges, and the tires being often as much as 7½ inches wide, so as always to be on the curve. The experiments made on the Mexican line were between an engine of the Baldwin type, and a Fairlie; which on this line alone had been used on a very large scale, and had proved, as far as its power was concerned, very superior to any other. The Fairlie engine, with a load of 70 tons on twelve driving-wheels, 8 feet 3 inches coupled wheel-base, took up an incline of 14 miles of 1 in 25 with continuous 325 feet curves, more than 153 tons, or about one-fifth more than double its own weight. The Baldwin engine, with 45 tons, on eight driving-wheels with 7½-inch flanges, the flanges being removed from the two pairs of inner drivers, with a coupled wheel-base of 14 feet 10 inches, took 50 tons gross. The area of the four Fairlie cylinders was as 5 to 4 of the two Baldwin cylinders. But an important point was that the expenditure of fuel for the Fairlie engine was as 3 to 2 for the Baldwin. The Fairlie engine in 29 miles, rising 4,014 feet, and returning, used 6,000 lbs. of coal. Thus the ordinary

locomotive ascending gradients of 1 in 25, and traversing 350 feet curves, did not take up twice its own weight, while the Fairlie locomotive on the same road took up from $2\frac{1}{5}$ to $2\frac{7}{10}$ its own weight. The Baldwin locomotive in Brazil, on the small line, took its own weight up an incline of 1 in 12, with 83 feet curves. On the Hartz line, the locomotive took up inclines of 1 in $16\frac{1}{2}$, with 590 feet curves, from 2 to $2\frac{1}{3}$ times its own weight. On the Puerto Cabello line, by adhesion, the locomotive took up inclines of 1 in 29, with curves of 300 feet, $1\frac{1}{2}$ to $1\frac{4}{5}$ time its own weight; by rack, it took up an incline of 1 in $12\frac{1}{2}$, with curves of 500 feet, from $1\frac{1}{8}$ to $1\frac{3}{8}$ its own weight. On the Rimutaka line, the Fell locomotive took up inclines of 1 in 15, with 330 feet curves, from $1\frac{1}{2}$ to $1\frac{4}{5}$ its own weight. Of course, the greatest advantage with the centre-rail system, whether the Fell or the rack, was experienced in times of frost, or when the rail was greasy. The report on the Mexican Railway, to which he had referred, appeared to have originated in a divergence of opinion, which resulted in valuable information being obtained. The Simla authorities had recommended the Abt system for the Bolan Railway, and the home authorities had recommended the Fairlie system. Sir Guilford Molesworth had compared the Abt and the Fairlie engines, and the results obtained by him were as given in the Table on the next page.

It appeared to him from the Papers, and from other information received, that any special system, whether the Fell or the Abt, for gradients steeper than 1 in 40, was preferable to ordinary adhesion, giving better results and greater economy. That was proved amongst other things by the statement of Mr. Maxwell, that the engine worked by adhesion only would take up 30 tons, and by centre rail only it would take up 40 tons, so that a great deal more was done by the centre rail on the same incline than by the ordinary rails. Mr. Wilson had stated that comparisons were fallacious when they were not on the same basis, and he certainly thought no comparison could be made between the Abt and Fairlie systems from the working on the Rimutaka incline. A glance at the figures would show this at once. The whole incline was 3 miles, including the station-yards. The train-mileage was given at 10,859, or 3,620 trains over the 3 miles. The net load carried was 50,000 tons, or only 14 tons net load per train, the maximum gross load being 70 tons. Taking the gross load carried at double the net, the Rimutaka average would amount to 40 per cent. of its maximum train-load; that of the Hartz amounted to 87 per cent. That the former figures were abnormal was also shown by the engine-mileage, which was 50 per cent. more than

COMPARATIVE PERFORMANCE of ENGINES of the ABT and the MEXICAN TYPES at LOW SPEEDS.

—			Abt.	Mexican.
Weight of engines		tons	53	72
Weight available for adhesion		,,	41·34	72
Diameter of cylinder		inches	18·896	16
Stroke		,,	23·622	22
Effective mean pressure		lbs. per sq. inch	90	90
Diameter of coupled wheels		inches	51·182	42
Tractive force adhesion		lbs.	14,882	24,179
,, ,, pinion		,,	14,062	..
Total tractive force		,,	28,944	24,179
Adhesion in frost		tons	3·69	6·43
Traction for pinions		,,	6·28	..
Total traction		,,	12·92	10·79
Gradient 1 in 40, summer	Total load[1]	,,	486	407
	Net ,,	,,	433	335
	Relative haulage		1·29	to 1·00
	,, efficiency		1·75	to 1·00
,, 1 in 25, summer	Total load	tons	300	251
	Net ,,	,,	247	179
	Relative haulage		1·38	to 1·00
	,, efficiency		1·87	to 1·00
,, 1 in 40, winter	Total load	tons	375	242
	Net ,,	,,	322	170
	Relative haulage		1·89	to 1·00
	,, efficiency		2·57	to 1·00
,, 1 in 25, winter	Total load	tons	232	149
	Net ,,	,,	179	77
	Relative haulage		2·32	to 1·00
	,, efficiency		3·16	to 1·00
,, 1 in 20, winter	Total load	tons	188	121
	Net ,,	,,	135	49
	Relative haulage		2·76	to 1·00
	,, efficiency		3·74	to 1·00
,, 1 in 15, winter	Total load	tons	143	92
	Net ,,	,,	90	20
	Relative haulage		4·5	to 1·0
	,, efficiency		6·11	to 1·0

the train-mileage. It was a pity Mr. Maxwell had not explained the cause of this. Though either the Fell or the Abt system might be good for steep grades, yet the time-honoured system of rope-traction, as now developed and improved with endless steel ropes and modern brakes, was better than any, and should receive far more attention than railway engineers had yet given it.

[1] "total load" includes the weight of engine. The "net load" includes the weight of the wagons hauled, with their contents.

Mr. D. M. Fox said he was sure that in a discussion on steep Railway Inclines the omission of any reference to the inclined planes of 1 in 9·75, worked by fixed engines and ropes, on the São Paulo Railway, Brazil, would be regretted. These inclines, surmounting a height of 2,650 feet in 5 miles, were originally laid out by himself for Sir James Brunlees, so long ago as 1857, and in a Paper which Mr. Fox had written "Description of the Line and Works of the São Paulo Railway, in the Empire of Brazil,"[1] in 1870, a full description was given of their construction and of the mode of working. The line was completed and opened for traffic in 1867, and in a communication in November 1880,[2] he had given the results after ten years' working, as he was now in a position to do for over twenty years. It was satisfactory to be able to record that, during this long period, no less than 2,600,000 passengers, and about 4,000,000 tons of goods, had been carried without the loss of a single life, and, indeed, without any accident of importance, attributable to the system of traction; whilst he ventured to assert that the figures he had compiled, from official returns, would show that this large traffic had been transported over the inclined planes at a less cost per unit of work done than could have been accomplished by any other system of working steep inclines. But before showing how those results justified Sir James Brunlees in adopting the old-fashioned rope system, he wished to make a brief reference to the Papers that had been read. The first, by Mr. Carruthers, related to the location of railways, and raised the question whether it was best to have a uniform gradient over the whole distance, or follow the valley with locomotive gradients as far as possible, and then rush up with a short steep incline requiring special tractive power. Of course that could only be decided on local reasons. It might have been thought that, where there was an almost exact coincidence of length (within 100 feet), Mr. Carruthers would have preferred a line of uniform gradient; but there were no doubt good reasons—such as the expensive works, the danger of land-slips, and the curves—that led him to follow the valley with locomotive gradients, and then climb the mountain with a steep incline. Still, as Mr. Sawyer had said, the whole had been spoiled by the Cambur piece, where the gradient was 1 in 29. If the line could have been made with a maximum gradient of say 1 in 75, or 1 in 50, going into the gorge to the foot of the mountain, then straight up it with a steep incline, that would have been the

[1] Minutes of Proceedings Inst. C.E., vol. xxx. p. 29.
[2] *Ibid.*, vol. lxiii. p. 128.

Mr. Fox. most economical way of working it. The São Paulo Railway was an entirely different case. It started from a sea-port, traversed a marshy plain for about 12 miles, and was then confronted with a gigantic sea cliff—it could be called nothing else—known there as the Serra do Mar—at right-angles. There was no valley running from the interior to the sea; there was a plateau at the top, and nothing could be gained by tunnelling. Every mile, therefore, of development on the ascent lengthened the line directly in proportion to the gradient adopted. There was a limited capital, and the concessionary said that not a penny more must be asked for, and the distance must not be increased. Sir James Brunlees accordingly adopted, at Mr. Fox's suggestion, the 1 in 10 inclines. If there had been a valley running into the interior, or if the range had been oblique to the direction of the line, so that the line could have been carried sideways up the Serra, Mr. Fox should have recommended a locomotive line; but, under the circumstances, he thought it would be admitted that Sir James Brunlees was decidedly right in shortening the ascent by the inclines of 1 in 10, to be worked by fixed engines and ropes. In 1857 the rack-and-pinion, central rail, and other contrivances were not known. The disadvantage of such systems of traction was that, first of all, the necessarily ponderous engine had to drag itself up the incline, and this involved the raising of 50 per cent. additional dead-weight. All that was saved by the rope system, where the motive power was housed, except the weight of the special brake to which the rope was attached, and the weight and friction of the rope itself. In reading the account of the Hartz (Abt) system in the second Paper, he at first thought there must be something extraordinary in it, as the cost of working per train-mile, 1*s.* 0½*d.*, was so very low. But the section of the line (Fig. 4) showed that the Hartz Railway was an undulating line, and it was worked partly by adhesion, and partly by the rack-and-pinion system. Of course, by mixing the abnormal incline work with ordinary locomotive work, the cost was brought down very much; but a comparison could not be fairly made with a fixed steep incline like the São Paulo, without taking the same proportion of locomotive line added to it, so as to average the expenses. Allusion had been made to the extraordinary prejudice against the rope. It was not confined to England. When the inclines were first opened in São Paulo, the Brazilians dreaded to go on them, not liking, as they said, to be hung on a rope. That reminded him that, in a comic paper, published in São Paulo, there was, shortly ofter the opening of the railway, a clever picture of a man with a rope round his

neck on the gallows, and another of a train going up the incline with a passenger in evident fear looking out. The question was asked: "What is the difference between a man going to be hanged, and a man going to travel on the São Paulo Railway?" and the reply was: "One prays that the rope will break, and the other prays that it will not!" Nor was this fear confined to the Brazilians. Even the celebrated traveller, Sir Richard Burton, in his book on the Highlands of Brazil, thus referred to the inclines: "The four terrible inclined planes—those glissades of death which make the stranger 'squirm'—on the Santos and São Paulo Railway." "Glissades of death," indeed! when, as had

SÃO PAULO BRAZILIAN RAILWAY.—COST OF WORKING the SERRA INCLINES (FIXED ENGINES and ROPES).

Gradient, 1 in 9·75; length of inclines, 5 miles; number of inclines, four; height surmounted, 2,650 feet; cost of coal per ton, 35s. to 40s.

—	1870. Estimated.	1880. Actual.	1888. Actual.
Average number of trains per day . . . . . . up	20	16·5	36
Average number of trains per day . . . . . down	20	16·5	36
Total average number of trains per day	40	33	72
Average number of vehicles per day	40×3=120	33×3=99	72×3=216
Average gross weight in tons raised and lowered 2,650 feet per day, say	1,040	850	1,890
Average paying load, tons per day, say	600	495	1,080
Average number of train-miles per day	200	165	360
	Coal. Tons. / £ s. d.	Coal. Tons. / £ s. d.	Coal. Tons. / £ s. d.
Average daily cost of running—coal, stores and wages .	7 / 29 14 0	5·75 / 22 18 4	10 / 36 10 0
Average daily cost of repairs and renewals—stores and wages	10 0 0	6 17 4	17 10 0
Average daily cost of tractive power	39 14 0	29 15 8	54 0 0
	d.	d.	d.
Cost per train-mile	47·6	44	36
" " vehicle-mile . . .	15·9	14·7	12
" " gross ton-mile . .	1·8	1·7	1·4
" " paying ton per mile .	3·17	2·9	2·4

Mr. Fox. been shown, not a single life has been lost in the twenty years since the opening of the line. But this prejudice had been overcome, and the Brazilian engineers were now coming round to the fixed-engine and rope system, having seen how successful and economical it was on the São Paulo line, and were admitting that it would have saved money if it had been adopted on their own State line—the Dom Pedro II. Railway. That was, he thought, a great triumph for Sir James Brunlees and the engineers who had carried out his plans. In the Paper on the São Paulo Railway, which had been read in 1870, he had made an estimate (based on the experience of two years) of the cost of working a given traffic up and down the inclined planes, as compared with what it would have been by means of a locomotive line of 1 in 40 His figures were criticised at the time, and said to be too favourable to the rope and fixed-engine system. But the Table on the previous page, giving the cost of working the Serra Inclines, as estimated by him in 1870, and from actual working in 1880 and in 1888, showed that in 1870 he had rather over- than under-estimated the cost of working them.

Considering that the price of coal in São Paulo was 35*s.* to 40*s.* per ton, as against 17*s.* 6*d.* in New Zealand, and probably 8*s.* to 10*s.* on the Hartz Railway, he thought these figures compared very favourably indeed with the cost of working steep inclines by the rack-and-pinion, or Abt system, and still more so by the Fell, or centre-rail system. As to the capacity of the inclines, as at present worked, they were equal to an annual goods traffic, besides passengers, of say 300,000 tons down, and 350,000 tons up, or 650,000 tons up and down, working from daybreak to sunset; and nothing could be easier than to add at least 50 per cent. to this by lighting the inclines throughout with electricity, thus making their capacity practically about 1,000,000 tons per annum.

Mr. Mosse. Mr. J. R. Mosse asked for more information about the cost of the rack and of the locomotive on the Trincheras incline. He also wished to know the gauge, and whether the pinions worked well, or were constantly breaking. With regard to the speed, the pinion-wheels were only 2 feet 2 inches in diameter, and clearly, therefore, the speed must be very low. He agreed with Mr. Carruthers that, if a gradient could be driven into a corner and then a rush made, this course was often advisable; but on account of the nature of the country, or the districts to be served, it was generally impracticable to do so. In long inclines often very difficult ground was encountered, and the roads were frequently subject to slips. On the extension of the Ceylon Government

Railways,[1] which reached a height of 5,300 feet, there were many Mr. M slips, and there were continual curves of 5 or 6 chains radius. The ground generally sloped from 1 in 2 to 1 in 4; consequently the cuttings were very deep. The line rose 40 miles with a gradient chiefly of 1 in 44; and was being continued on to a summit of 6,200 feet above the sea with curves of 5 and 6 chains radius; the gauge was 5 feet 6 inches, and the line was worked very successfully by ordinary locomotives. It might be interesting to compare the results of working the Midland line of the Mauritius Railways,[2] with that of the Trincheras incline. By ordinary locomotives on the former line a gross load of 800 tons of goods a day was taken up an incline rising 1,800 feet in 16 miles, and falling the same distance on the other side. One point with reference to the rope system had not been touched upon, which he thought was of great importance. If only the engine was made powerful enough, any ordinary train could be taken up by it. With the other system, it was necessary to be constantly increasing the number of locomotives. He had been a railway manager on steep inclines, and knew how much trouble there was in having the trains limited. If two or three extra wagons were put on, it was often necessary to have an extra engine. With the rope system, and a sufficiently powerful engine, the working was not cramped in the same way as by other systems. He therefore thought that the rope system had a very great advantage over the Fell or Abt systems.

Mr. EDWARD PRITCHARD said that his chief experience had been Mr. in connection with tramways and rope-traction. On tramways a 10-ton engine had succeeded in ascending gradients of 1 in 15, carrying 5 tons exclusive of passengers. With regard to rope-haulage, he thought it must be admitted that what would be one of the best means of travelling over severe gradients had been lost sight of. Reference had been made to ropes used both in this country and in America; but he gathered that the ropes used in this country had been tail-ropes, so that it was impossible to have the full effect or benefit of the rope-haulage. A rope must be a continuous one to work economically; in other words, the loads should be balanced, and the greatest friction to be overcome the rope itself and the machinery. Two years ago he had the satisfaction of making a professional inspection of nearly every cable tramway in America. He had seen the ropes in San Francisco, and noticed the very steep gradients there, and could confirm the statement

[1] Minutes of Proceedings Inst. C E, vol. lxiii. p. 63.
[2] *Ibid* vol. xxviii. p 232.

Pritchard. that there was no danger of the rope breaking. He might be permitted to give one illustration. On the inspection of a cable line with which he was connected in Birmingham, the Board of Trade Inspector was anxious to know what would be the result of a rope breaking with the various cars attached to it. From information that he had obtained in the States, he remarked that the cars would simply cease running, and that the conductors or brakesmen would apply the brakes. The engines were then running at full speed with cars attached, and he so slackened the tension that the driving-wheel which operated the rope continued rotating, but in consequence of the tension being reduced, the cable immediately became stationary although at the time the experiment was made there were five or six cable cars attached by their grippers to the rope. Allusion had been made to the system of rope-haulage at Highgate, but he was astonished that the roads in Edinburgh and Birmingham had been overlooked, because he believed they were superior to the majority of the roads in America; they were certainly greatly superior to many that he saw there two or three years ago. The Birmingham line was one of the most difficult roads to work, both for its lateral and vertical variations. There was a curve subtending an angle of about 90° on a rising gradient of 1 in 15, and having a radius of 57 feet 6 inches. He had alluded to the tail-rope not giving good results, and he would now refer to the disadvantages of a continuous rope. The friction was enormous. He had frequently known, with $2\frac{1}{2}$ miles of rope, something like 79 or 80 indicated HP. absorbed, and by putting on eight cars, each weighing from 5 to $5\frac{1}{2}$ tons, exclusive of passengers, the indicated HP. had not been more than from 84 to 85, showing that the loss was very great in the first instance. That was upon a very difficult portion of the road, $2\frac{1}{2}$ miles of single road, to be connected shortly with another $4\frac{1}{2}$ miles of single road, being worked from the same machinery. Although, in one instance, 70 per cent. of the power might be absorbed in moving the idle-rope, he believed not more than 50 per cent. would be absorbed in moving the other, consequent upon the conditions of the roads and the methods of construction. When there was a tortuous road, such as the one he had referred to, the power expended was very great; but even then, with continuous or constant service of the loads at equal distances, they could be worked much more cheaply than it was possible to work with a locomotive engine. At Birmingham, the cost of working on some of the steam roads having gradients of 1 in 19, and sometimes very greasy, was $3\frac{1}{4}d.$ per car-mile, including wages, fuel, oil, and repairs; the weight of the train, one engine and one car, being from 15 to 16 tons.

With regard to the rope itself, much would depend upon its construction. He had seen ropes in San Francisco which had been in use for twenty-six months, made of British wire, while other ropes, made of American or German wire, had been destroyed in much shorter periods. The best ropes he had seen in the United States were those made by Mr. Hallidie, who had been called the father of cable-traction; but he had learned, at the Patent Office at Washington, that an Englishman, not an American, was the father of cable-haulage. He believed that the question of rope-haulage had yet to come to the front, and he hoped it would have the support of engineers in this country which it deserved.

Mr. J. W. MITTON WATSON observed that many years' experience in the construction of very steep gradients in Europe, Asia, and South America, together with his having recently had an opportunity of inspecting the Rigi, the Brunig, and the St. Gothard railways, had led him to believe that in setting out a very steep incline, the question of curves might, under some circumstances, become almost as important as that of grades. He could best show the reason he had for forming that opinion, by comparing two of the most remarkable railways that had come under his own immediate attention. One was the Oroya Railway, in Peru, which, starting from the wharves at Callao, attained by means of a gradient of 1 in 25 an altitude of 15,500 feet above the level of the sea, nearly the height of Mont Blanc. The other was the St. Gothard. Both were worked by the ordinary traction system, and were of the ordinary gauge, and in each the difficulty had been to surmount a great height within a short distance. On the Oroya Railway,[1] it was considered advisable, even with several viaducts, nearly sixty tunnels, and curves of only 120 feet radius, to use frequent reversing stations, which were always in themselves dangerous and objectionable. On the St. Gothard Railway, these were altogether avoided by the adoption of circular spiral tunnels; but their great cost would probably, in many instances, prevent a railway from ever being made. If with the steep gradients on the Oroya Railway sharp curves could be successfully worked, most of the reversing stations might have been done away with; while the spiral tunnels on the St. Gothard Railway, even if not altogether avoided, might at any rate have been materially shortened. These facts led him to believe it would be of great general utility if some reliable information could be given as to the smallest radii with which each of the systems under discussion could be advantageously

[1] Minutes of Proceedings Inst. C.E., vol. lxiii. p. 145.

atson. worked, and he felt sure that many members of the Institution, besides himself, would be greatly obliged to any one who would furnish such information.

Vilson. Mr. ROBERT WILSON, in reply, was unable to state definitely the reasons why Mr. Carruthers had adopted the 3½ per cent. gradient from Cambur to Trincheras. He was under the impression that it was a question of first cost, combined with the topographical features of the valley. Mr. Fell had asked why the engines were not run over a longer portion of line than the mere incline, on the Rimutaka. It was pointed out in the Paper that the weight of the rails precluded the possibility of running the engines over the other portions of the line. Mr. Fox had objected to the compared cost of working on the Hartz line with that of the Fell system. The Paper was, perhaps, not very clear on this point. He had not intended to institute a comparison of the cost of working the Hartz line and the Fell incline, but rather to point out that a saving was to be obtained by adopting the adhesion and rack system combined in running over a line of that description; and he had in his mind the Rimutaka incline, knowing that if it had been possible to run the trains beyond the incline, it would have materially reduced the cost of working. With regard to the Hartz line and the incline worked on the Fell system, he had attempted to make a comparison to show, that even reducing them both to like conditions there was something in favour of the Hartz, due, no doubt, to the possibility of working the trains continuously over the line. On the Hartz Mountain Line the maximum adhesion gradients were 1 in 40, and the maximum rack gradients 1 in 16·67. The adhesion sections were 14½ miles and those with the rack 4·7 miles in length. For the round trip, that would be 28·5 miles of adhesion, and 9·4 of rack. The coal-consumption on the round trip was given at 1,845 lbs. Assuming that the consumption of fuel on the adhesion sections was 30 lbs. per mile, which was a low estimate, it would give, for the round trip of 28·5 miles, 855 lbs., leaving 990 lbs. for the rack sections; equal to 105·4 lbs. per train-mile. On the Rimutaka incline the consumption per engine-mile, according to the government returns of 1888, was 112·43 lbs. The mileage was thus made up: 10,988 train-miles, 4,233 shunting-miles, 21 ballast-miles; total 15,352. The coal consumed was 766 tons. The shunting-mileage was made by the Fell engines, not on the incline, but in the station-yards at the top and bottom; and for comparison it might be assumed that those engines would burn 30 lbs. per mile for that duty. The inside engines would not be at work at the time. That would absorb a coal-consumption

of 126,990 lbs., leaving a balance of 1,588,850 lbs. for the incline. That divided by the train-mileage would give 144·2 lbs. But the Fell engine took 65 tons up 1 in 15; it would take 75·6 tons up 1 in 16·67, the Hartz grade. The Abt engine took 95·5 tons; therefore, if the coal consumption were taken directly as the load, the proportions would be, as 75·6 to 95·5 tons, and 144·2 to 182·1 lbs. But the coal in New Zealand had not the same evaporating power as that used on the Hartz. New Zealand coal would evaporate about 7 lbs. of water for 1 lb. of coal, and that used on the Hartz about 8 lbs., so that the consumption would be reduced on the incline itself to 159·3 lbs. for a 95-ton load against 105·4 lbs., or a difference of 53·9 lbs. per train-mile. Assuming that the two systems were equally efficient, the 53·9 lbs. represented coal burned without earning mileage. From this it might be deduced that the Fell engines on the Rimutaka incline consumed about 13 lbs. more coal per train-mile, under present conditions, than they would if kept fully employed. He thought that those figures justified him in having stated in the Paper, that if a line was laid out necessitating the use of a bank-engine, at one or several points, increase of cost of working must ensue, unless the traffic were such as to keep the bank-engine in constant use. There was thus a great advantage in the combined adhesion- and rack systems, which enabled the same engine to take the load over the entire line, notwithstanding exceptional grades on various sections. He did not wish to advocate any special system for working inclines. He took great interest in the question, and thought that probably for one line the Abt system might be more effective, and the Fell for another, or rope-traction for a third; but must in fairness state that after considering the mechanical details of each, he had come to the conclusion that the Abt system would best meet the requirements of railway-incline traffic both as regarded cost and safety. He did not think there would be a material difference in the curvature round which the Abt or Fell engines would run satisfactorily. He thought the limit of curvature for the Abt system would be governed by the clearance of the pinion teeth in the racks, and the radius at which that was arrived at would be far below the limits of practical application to railways.

Correspondence.

Mr. Abt. Mr. R. Abt considered that, after the investigations made by Messrs. Livesey and Son, the adoption of a locomotive purely of the rack-rail type for the incline at Las Trincheras was advisable. In general, however, for such lines this was not the case. As shown by experience, supported by theory, the principle of the division of labour was the best, even when applied to the construction of locomotives for mountain railways. As early as the year 1882, when occupied in working out his rack-rail system, Mr. Abt had formulated the principle that the rack should not have to bear the whole force required for the propulsion of the train; but that as much force should be taken up by the ordinary rails as corresponded with the adhesive weight of the locomotive. The correctness and appropriateness of this principle was now generally acknowledged. Locomotive-builders would not easily produce anything superior to the present adhesive locomotive. It would therefore be a mistake to ignore this excellent machine. A perfect rack-rail engine must, in the first place, be a good adhesive engine, and the toothed wheels should only make the adhesive action reliable and, up to a certain point, supplement it. On the railway in question, trains of 68 tons were taken by a locomotive weighing 40 tons up a gradient of 8 per cent. The whole train caused a resistance, in round figures, of 9·4 tons. From a constructive point of view, it would not be impossible to make the necessary machine as a six-coupled tender engine. Under ordinary conditions, it would then have a tractive force from adhesion of 5 to 7 tons, so that for the spur-wheel and rack there would only remain a supplementary effort of about 4 tons. In this way the work would be distributed over 6 points on the rails and 2 points on the rack, or 8 points in all, which, in respect to safety, maintenance of permanent way, and cost, was obviously preferable to a concentration on 2 points only. He had noticed with pleasure the remarks of Mr. Carruthers on the admissibility of curves with small radius on lines constructed on the Abt principle; and was glad to be able to state that these views were completely justified. No doubt in most cases the gauge of the line, the existing rolling-stock, or that coming from other railways, would prohibit the adoption of sharp curves; but where this was not the case, other portions of the structure limited the minimum radius of the curves before, or at any rate simultaneously with the rack. As illustrations, he would refer to three railways which he was then constructing: One was the line from Eisenerz

to Vordernberg, in Styria, the construction of which was directly superintended by the Austrian Government. This railway, which was about 20 kilometres in length, and of the ordinary gauge of 4 feet 8½ inches, served in the first place for the local transport of ore, but was also used for general traffic; therefore it must be passable for all vehicles of the ordinary lines, in consequence of which the minimum radius was taken as 180 metres (say 590 feet). The steepest gradient was 2·6 per cent. with adhesion only, and 7·1 per cent. with the rack. The annual traffic was at least 320,000 tons of goods, besides a considerable number of passengers. Here, therefore, the ordinary vehicles determined the minimum curves. The line Visp-Zermatt, in Switzerland, had a length of about 36 kilometres, a gauge of 1 metre, and maximum gradients of 12 per cent. This railway was to serve almost exclusively for passenger traffic. The minimum radius for the rack was assumed at 100 metres (say 328 feet). Of the whole length, 7 kilometres, in six different portions, were furnished with the rack. This, like the preceding line, would be worked by combined adhesion-and-rack locomotives on the Abt system. The line from Capolago on the St. Gothard Railway, to the summit of Monte Generoso, had a gauge of 80 centimetres (31·5 inches), a maximum gradient of 22 per cent., was purely of the rack-rail type, and had special rolling-stock. On this railway there were many curves of 60 metres (say 197 feet) radius, a minimum which, with the steep gradient and the transport of passenger-carriages with 60 seats, would certainly not have been advisable without the rack. Mr. Abt.

Mr. P. A. FRASER observed that Mr. Carruthers had brought forward a subject of increasing interest for engineers, for, as he justly said, the use of steep inclines on railways to replace long gradients had not been sufficiently considered. Mr. Fraser's own experience in Mexico and South America confirmed this. Having, the request of the Venezuelan Government, inspected the routes the Puerto Cabello Railway in 1884, he was strongly impressed ith the suitability of the valley at Trincheras for an inclined ne, and he then endorsed the Author's suggestion, which had since been so successfully carried out. Although the "Palito" route was clearly the best "pioneer" route of the two, he believed that as Venezuela progressed, and traffic developed, another line, with uniform and easy gradients, such as the "Guaiguaza" route, would also be imperative, even should the prime cost be much greater. As the Resident Engineer for the completion of the La Guaira and Caràcas Railway, he became aware that there also an inclined plane might have been adopted, with the advantage over Mr. Fra

Fraser. the Puerto Cabello railway of concentrating all the steep gradients at one point, and also of shortening the total distance. On the Mexico and Vera Cruz Railway, again, a remarkable economy on prime cost, on distance, and on cost of haulage, might have been effected by substituting an inclined plane of something over 1½ mile in length for some 13 miles of gradient of 1 in 25. That line had been admirably located by American engineers in 1857, and the progress of engineering in the interval rendered it almost certain the inclined plane would now be adopted. Last year, while surveying for a railway to connect the towns of Salta and Jujuy in the Argentine Republic with Potosi in Bolivia, he came upon a point where an inclined plane was not an alternative line, but the only possible one. Although for other reasons this project had dropped, this would have been a remarkable instance of the value of such communication between two plateaus differing by a height of over 3,000 feet in level. Mr. Carruthers had alluded to the great interruption of traffic on the La Guaira and Caràcas Railway from landslips. Admitting this to have been the case, it must not be inferred that landslips were to be dreaded more, or even as much, in the tropics as elsewhere. The La Guaira Railway was finished at very high pressure, and he might say was opened for traffic before it was finished. There was neither time nor opportunity for executing all such works as would have rendered landslips impossible or harmless. Had a fraction of the same expenditure or attention been given to covered galleries, retaining-walls, pitching of slopes, and defence works, even of the simple nature of planting and sowing, as was usual in Austria, Switzerland or Italy, upon mountain railways, the incessant interruption of traffic and reconstruction of roadbed on the Caràcas Railway would have been unknown. The Venezuelan Government desired the line to be opened in time for the festival of Bolivar's centenary, and everything had to give way to this. No such landslips occurred on the Mexican Railway, where worse cuttings presented themselves, from the fact that years elapsed during the construction of the line; and the tropical vegetation so completely and spontaneously covered the exposed surfaces that little further consolidation was necessary. As regarded the working of the Palito line, he was glad the Heberlein brake was in use. The service this brake had rendered on the La Guaira and Caràcas Railway, in arresting runaway trains and wagons, and in preventing innumerable accidents, was inestimable.

McDonnell. Mr. ALEXANDER McDONNELL stated that he had visited Brazil last summer, and had examined the working of some of the steep

inclines in that country. The incline up the Corcovada was not very well laid, and during the time he was there the train slipped twice. He mentioned this as showing that such a system required care in construction and in working. The incline on the Petropolis line was better laid, and worked smoothly. Nevertheless an engine had run off the line not long before he was there, and went some distance down the side of the mountain. He could not learn the cause of the engine leaving the line; but every care should be taken against such an accident, as in such a situation the result might be very serious. If anything went wrong with such a train, the first thing the men in charge thought of was to jump off, which, as the speed was not great, they could often do. It was therefore highly expedient to make the control of the train easy, and where possible, automatic. On the Cantagallo line, which now formed part of the Leopoldina system, there was an incline between Cachocira and Nova Friborgo of 10 kilometres ($6\frac{1}{4}$ miles) of 1 in 12. This incline was formerly worked on the Fell system, but was now worked by ordinary locomotives. The engines were very powerful, with cylinders 18 inches in diameter, and wheels 3 feet 3 inches; the rigid wheel-base was 10 feet. They weighed about 45 tons, and took about 40 tons up the incline. The engines were built by the Baldwin Company, of Philadelphia. They were very well adapted for the work. The consumption of coal was from 25 to 27 kilograms per kilometre (88 to 96 lbs. per mile), the consumption on other parts of the line varying from 9 to 11 kilograms per kilometre (32 to 39 lbs. per mile). The average trains up the incline were 4 carriages for passenger-trains, 4·36 for mixed trains, and 4·90 for goods. These were the loads, loaded and unloaded wagons mixed. The central rail of the Fell system was still used for applying the brake when coming down the incline. There was one engine of the Fairlie type; but it had only run 95,732 miles since 1873. He thought that engines of this type, if properly designed, would be well adapted for working such inclines. From Cachociras to the top of the incline the distance was 32 miles, of which nearly $1\frac{1}{4}$ mile was level; about 6 miles on a gradient of 1 in 12, and $5\frac{1}{4}$ miles on 1 in 14 and 1 in 33, with some curves of 130 feet radius. The Leopoldina Railway had no such gradients as 1 in 12; but there were some steep gradients with curves of 260 to 330 feet radius. In a total length of 355 miles, there were $71\frac{1}{2}$ miles of ascending, and 51 miles of descending gradients of 1 in 40 and 1 in 50. Most of the engines were American, built by the Baldwin Company. Those with six wheels coupled weighed 20 tons, with 16·75 tons adhesive weight; those with eight wheels

McDonnell coupled, 26 tons, with 22·75 tons adhesive weight. Their cylinders were 13 inches in diameter, 16 inches stroke, and wheels 3 feet 3·4 inches in diameter. The eight-wheeled coupled engines had cylinders 15 inches in diameter, 18 inches stroke, and wheels 3 feet in diameter. The average loads were: passenger trains, 3·4 carriages; goods trains, 10·7 wagons; and the general average 6 vehicles. The consumption of coal was 8·65 kilograms per kilometre (30·7 lbs. per mile). The carriages and wagons had generally double bogies, the carriages taking from forty to fifty passengers, and the wagons from 8 to 10 tons.

Mr. T. M. Rymer-Jones. Mr. T. M. RYMER-JONES much preferred the customary system to the long valley level and then a sharp incline contouring system, since, among other advantages, by its use and an occasional bold bridge or short tunnel between two valleys, heading against each other, a steep incline might be avoided. On the road itself on steep inclines the creeping of the rails, which in expanding and contracting did not recover their uphill position exactly, caused them to lose ground, necessitating their re-setting. A severe continuous gradient, again, gave no chance of a fresh start, in the case of an overloaded train, or loss of steam on perhaps a misty, or for the rails a greasy, morning. In view of this state of the rails possibly occurring, catch sidings should always be provided at available points. Stopping with possibly too heavy a load, running back, or couplings breaking, or the train on coming down running away, rendered an accident highly probable on steep ghâts where a curve was anything like so sharp as 140 feet radius. In Mexico, curves of 330 feet radius were used on an incline of 1 in 25, with Fairlie engines; these acted well with thirteen wagons. A gentle incline moderated slips, whether of clay-slate or any other stone or debris, which meant a gain in maintenance over steep inclines. Round the spurs of hills, with a precipice possibly alongside, during the rainy season, clay-slate or new cut work, not perhaps thoroughly settled into position, was very liable to slip.

Mr. Schneider. Mr. A. SCHNEIDER, Director of the Halberstadt-Blankenburg and Blankenburg-Tanne Railway, stated that he had adopted the Abt combined adhesion and rack-rail system for the first time on the Hartz Railway from Blankenburg to Tanne. Without entering on a description of the construction of the line, he would give some particulars relating to it which might be interesting. The railway was traversed for the first time by experimental and working trains on the 15th of May, and was opened in sections for public traffic, the first to Rübeland, on the 1st of November, 1885. Since then the traffic had been carried on continuously with the greatest

safety and precision. On days when there was a heavy goods traffic, ten trains had been despatched each way between 5.30 a.m. and 9 p.m., or fifteen and a half hours, when the trains coming from the Hartz had always a gross load of 120 to 135 tons. The permanent way stood admirably, and the cost of maintenance was no greater than that of any line of ordinary construction. The wear of the teeth of the wheels of the locomotives was so slight, that a wheel of that kind could work very well for at least ten years; the teeth of the rack had shown no signs of wear as yet; by calculation the wear would be 1 millimetre (0·04 inch) in one hundred and fifty years. The evaporation in the locomotives with the four cylinders at work was enormous, so that a deficiency of steam on the ascending trip had never occurred; on the contrary, the engine-driver had always a surplus. With still heavier traffic it would be possible, by arranging for a night service, to despatch in twenty-four hours fifteen trains in each direction, or both ways a total of thirty. These might carry 1,800 and 3,600 tons gross load, or 1,200 and 2,400 tons net, respectively, amounting in one year of three hundred working days, to 360,000 and 720,000 tons net respectively. The system had given great satisfaction, and it was considered that by no other system of mountain railway could the same results have been achieved either technically or financially. The comparatively great extension of the Abt system during the few years of its existence was the best evidence of its efficiency in every direction.

Mr. W. SMITH, Aberdeen, had been consulted several years ago as to the most suitable scheme for the formation and working of a tramway to connect the town of Victoria, Hongkong, with Victoria Gap, the lowest summit of the precipitous hills above the town. Sections of the ground had been made by a local engineer, and on these it was proposed from the nature of the ground to form two detached lines of nearly uniform gradients, with a steam-engine and machinery for wire-rope traction at a station on level ground between the upper and lower lines. This scheme involved both cutting and embankment up to 70 feet depth on steep side-lying ground, estimated to cost £20,000. As an alternative he suggested the scheme which had since been successfully completed at a total cost, for the tramway and machinery, but little in excess of that sum, the gradients following very nearly the natural contour of the ground. The tramway was laid down from St. John's Place, Garden Road, to Victoria Gap, a length of 4,690 feet, the height of the upper above the lower terminus being 1,207 feet. The easiest gradient was 1 in 25 and the steepest 1 in 2. To insure economy of

ith. first cost and maintenance of permanent way, the natural surface of the ground was adhered to as closely as possible. There were eleven bridges under the line, ten being formed simply of rolled-iron girders laid down on stone piers, the remaining span requiring 40-foot girders. All the embankments had to be pitched with stone on account of the rainy climate. The line was single on the lower section, double with a 6-foot way at the passing place of the cars, and double with three rails and no central way above the passing place. The rails were flat-bottomed bulb steel rails, weighing 35 lbs. per yard, laid to a gauge of 5 feet, fastened down to cross-sleepers weighing 24 lbs. per yard, bedded on lime concrete 6 inches thick. The sleepers were fastened to the rails according to the Le Grand system.[1] The carriage bodies were built in Hong-kong of timber, mounted on steel bogies, and carried forty passengers each, weighing when loaded between 5 and 6 tons. The motive power consisted of two pairs of compound horizontal engines with multitubular boilers, each 40 HP. nominal, and erected at the upper terminus with the winding drums. These were cast-iron grooved drums without lining in the grooves, 8 feet in diameter, the upper drum having four and the lower drum three grooves. Motion was communicated to the carriages by a flexible plough cable of steel, 3¾ inches in circumference, tested to a breaking-strain of 54 tons. The rope was reeved over the winding-drums, and the carriages were attached to each end, so that while one train ascended the other was descending at the same speed, the two trains passing each other half way on a passing place 130 feet long, with points at the lower end. With the maximum load of one hundred and twenty passengers the greatest strain on the rope at the steepest grade was 7 tons. Bearing pulleys for the cable were bracketed on to the sleepers at distances along the line varying from 3 to 8 yards, and at the curves vertical guide pulleys were bracketed along with the bearing pulleys. The natural difficulties of construction were enhanced by the superstition of the Chinese workmen with regard to the supposed guardian of the soil, "Fung Shui." A short tunnel, proposed to ease the steepest gradient, had to be abandoned owing to the opposition of Chinese contractors. This necessitated the alteration of the automatic brake, from a safety rope controlled by automatic clips in the engine-room at the top of the incline, to a central-brake rail weighing 66 lbs. per yard laid along the middle of the track, gripped by two steel clip-brakes, arranged to grasp the brake-rail

[1] Minutes of Proceedings Inst. C.E., vol. lxvii. p. 51.

constantly unless held out of action by the brakesman. These brakes were supplemented by similar brakes on the 35-lb. rails. There were two curves on the line; starting from the lower terminus it proceeded 400 feet in a south-west direction, turned by a curve of 500 feet radius to south-south-west, in which direction the line continued to an altitude of 900 feet, when a curve of 300 feet radius changed its direction to due west up to the upper terminus. Nearly the whole line was visible from the upper terminus; the brakesman could signal to the engine-driver at the top from any part of the line while the cars were in motion, and there was telephonic communication between the termini. By a pair of pointers travelling along a rectangular dial in the engine-room, and geared off the winding-drum shaft, the exact position of the cars in motion on the line could be seen by the engine-driver. The maximum speed was 7 miles an hour, reduced to 4 miles at the points and crossings, and the journey between the two termini occupied ten minutes without including stoppages at intermediate stations. The chief feature in the line was the extreme variation of the gradients, from 1 in 25 to 1 in 2, an important consideration in regard to first cost; but this variation did not interfere with the comfort of the passengers. The effect of the extreme steepness of the gradient of a short part of the line with a flat grade above, over which the descending car passed while the up car was on the steepest grade, was to limit seriously the weight of trains hauled up the line. The ideal section would be one where the steepest grade was at the upper terminus, gradually easing off to nearly horizontal at the lower terminus. This was not obtained on the Hongkong high-level tramway, and it was intended to rectify the route when land adjacent of suitable levels could be acquired. On the existing gradients the maximum load was one hundred and twenty passengers; on the line of highest efficiency the load would be six hundred passengers.

Mr. Sn

5 February, 1889.

SIR GEORGE B. BRUCE, President, in the Chair.

His Royal Highness Prince Albert Victor of Wales, K.G., K.P., was elected by acclamation an Honorary Member.

The following Associate Members have been transferred to the class of

Members.

ROBERT JAMES FRECHEVILLE.
JAMES BERNARD HUNTER.
ROBERT KENNAWAY LEIGH.
RICHARD LIRON MESTAYER.
JOHN O'CONNELL.
RICHARD PAWLEY.
WILLIAM ARCHIBALD SMITH.
EDMUND HERBERT STEVENSON.
FLETCHER WILSON STEVENSON.
GEORGE ERNEST STEVENSON.
RICHARD TIPLADY.
JOHN WEBSTER.

The following candidates have been admitted as

Students.

ARTHUR ROBERT BARROW.
WILLIAM ALFRED BENNETT.
JAMES WILLIAM BRADLEY.
FREDERICK THOMAS BREARLEY.
EDWARD CANNAN.
WILLIAM REGINALD DARBY.
AUSTIN ARTHUR GREAVES DOBSON.
WILLIAM MORRIS GALE.
ISAAC BERNARD GODFREY.
EDGAR HENRY QUIXANO HENRIQUES.
REGINALD FRANCIS HICKMAN.
FRANK HOWARTH.
JAMES LEECHMAN, Jun.
ALFRED JAMES SHINE LEFROY.
JAMES ARCHIBALD MCNAB.
AFFONSO DE OLIVEIRA ALBUQUERQUE MARANHAO.
ALEXANDER MOIR.
WALTER ELPHINSTONE MUSPRATT.
SYDNEY ELLIOTT PAGE.
HARRY PENN.
WILLIAM CHARLES READING.
GEORGE THOMPSON ROBERTSON, B Sc.
WILLIAM HARRY RUNDALL, A.K C.
HENRY ARCHIBALD KERR SCONCE.
ALFRED WILLIAM EVANS STANDLEY.
PERCY STILL.
THOMAS VICKERS.
WILLIAM HENRY WILSON.
JOHN RUSKIN WORNUM.
HENRY HERBERT WYATT.
ALFRED ERNEST YOUNG.
JAMES YOUNG.

The following candidates were balloted for and duly elected as

Members.

JAMES ANGUS.
WILLIAM WIKELEY CLAYTON.
FREDERIC GEORGE FIS
JOHN HEAD.
ALBERT JOHN OLDHAM.
EDWARD REYNOLDS.
THOMAS EDWARD VICKERS.
ARTHUR MELLEN WELLINGTON.
JOSEPH HARTLEY WICKSTEED.

Associate Members.

PETER ROE BEDLINGTON.
SYDNEY LINTON BRUNTON, A.K.C., Stud. Inst. C.E.
THOMAS EDWARD CANDLER.
WALTER EDMUND COOK.
SIDNEY À COURT.
LEWIS MARIE THEODULE DEVÉRIA.
RICHARD DUFFY.
FREDERICK HENRY ENGLISH.
GEORGE BENJAMIN ALBERT GIBBONS.
HERBERT BOYS GREGSON, Wh.Sc., Stud. Inst. C.E.
THOMAS CHARLES JOHN HARRISON.
EDWIN HARRY ALFRED HEINKÉ.
MAURICE HUNTER, Stud. Inst. C.E.
THOMAS JEFFERISS.
WILLIAM EDMUND KEMP.
SANJIRO KIKKAWA, M.E.
HUGH MAIR.
DOUGLAS EARLE MARSH.
ERNEST WILLIAM MOIR.
JAMES SMITH MOLLISON.
EDWARD LESLIE ROBERT MUIR, A.K.C., Stud. Inst. C.E.
THOMAS MONK NEWELL, Stud. Inst. C.E.
JAMES PARKINSON.
ROBERT PEIRCE, Stud. Inst. C.E.
SAMUEL DE PERROT.
JOSEPH GORDON POPE.
GEORGE WILLIAM PORTEOUS.
HENRY SADLER.
CHARLES ROBERT BUNN DE LA SALLE.
WILLIAM ELOIN SANT.
ERNEST EDWARD SCHOLEFIELD, Stud. Inst. C.E.
FRANCISCO SCHUSTERSCHITZ.
MITSUGU SENGOKU.
EDGAR CHARLES THRUPP, A.K.C., Stud. Inst. C.E.
GEORGE FREDERICK TIPPETT.
EDMUND BROWNELL WESTON.
HENRY BOURCHIER WREY, Stud. Inst. C.E.

Associates.

FREDERICK BACK.
WILLIAM TERRELL GARNETT.

The discussion upon the Papers by Mr. J. Carruthers, Mr. R. Wilson, and Mr. J. P. Maxwell, on Railway Steep Inclines, occupied the whole evening.

12 February, 1889,
SIR GEORGE B. BRUCE, President,
in the Chair.

(*Paper No. 2363.*)

"Some Canal, River, and other Works, in France, Belgium, and Germany."

By LEVESON FRANCIS VERNON-HARCOURT, M.A., M. Inst. C.E.

ON the way to the International Inland-Navigation Congress, held at Frankfort-on-the-Main, in August 1888, the Author had an opportunity of inspecting some works in France and Belgium, as well as various others in the neighbourhood of Frankfort visited by the Congress. These works are almost all of quite recent date; and the Author thinks that brief references to them, besides possessing the interest of novelty, will serve to illustrate the progress being achieved by neighbouring nations, and to indicate the variety of works that may be easily visited during a brief tour abroad, which also comprised regular attendance at all the sittings of the Congress.

HYDRAULIC CANAL-LIFTS.

Plate 6, Fig. 1.

Fontinettes Lift.—This lift is situated about two or three miles from the St. Omer station, on the railway between Calais and Lille. It was designed to supplement a flight of five locks on the Neuffossé Canal, which connects the North Sea ports with Paris, as the trade along this canal has so much increased that the chain of locks is incapable of accommodating the traffic.

The lift, designed by Messrs. Clark, Standfield and Clark, for surmounting a difference of level of 43 feet, consists of two counterbalancing troughs, each resting on a central hydraulic ram, thus resembling in principle the Anderton lift designed by Mr. Edwin Clark.[1] The Fontinettes lift, however, is considerably larger than its prototype, as it accommodates barges of 300 tons, instead of only 100 tons: its troughs are 129 feet 7 inches long, 18 feet 4½ inches broad, and contain 6 feet 6¾ inches depth of water; and

[1] Minutes of Proceedings Inst. C.E., vol. xlv. p. 107.

its cast-iron rams have a diameter of 6 feet $6\frac{3}{4}$ inches, in place of the 3-foot rams at Anderton. The addition of a layer of 16 inches of water in the upper trough supplies an ample surcharge for overcoming the resistances, and effects the descent of this trough and the ascent of the other; and since the trough descends into a dry pit, from which the water in the lower reach is shut off by a lifting-gate, as at the entrance to the upper reach, the trough does not lose weight by immersion at the end of its descent, which is an important improvement on the Anderton arrangement. Accordingly, in theory, the surcharge introduced into the top trough would suffice to complete the whole operation; but a turbine has been provided, turned by a flow of water from the upper reach, which works a pair of hydraulic engines with accumulators. The first raising of a trough was thereby effected; and the accumulators serve to compensate for leakages in the presses, work the pump for keeping the pits dry, lift the counterbalanced gates at the extremities of the troughs and reaches, and turn the capstans placed on the quays at the entrances to the lift. The machinery is situated in a building erected in the space between the two trough pits. The upper part of the building provides a dwelling for the men working the lift; whilst at the summit, a look-out cabin contains the levers of the valve-machinery for controlling the motion of the lift. The troughs are maintained in position by central guides, sliding in grooves in the main building and side-towers adjoining the middle of the troughs. In order to prevent any swinging round of the troughs, guides have been placed at each side of the up-stream ends of the troughs, sliding against cast-iron plates let into the masonry pier supporting an aqueduct which, spanning a railway, connects the lift with the upper reach of the canal. Dimensions and other figures relating to this lift, furnished to the Author by Mr. Lyonel Clark, the Resident Engineer, are given in Appendix I.

The adjoining pair of gates, at each end of a trough and at the extremities of the canal-reaches, are locked together previous to being lifted, so that they may be raised simultaneously by chains from the frames erected at the extremities of the lower reach and the aqueduct, and thus dispense with frames over the ends of the troughs. This arrangement had led to a curious accident at the time of the Author's visit. Owing to the failure of the cast-iron presses at Anderton in 1882, the Fontinettes presses were made of weldless steel coils, with internal copper lining;[1] and the packing

[1] Minutes of Proceedings Inst. C.E., vol. lxxx. p. 401; and Le Génie Civil, vol. iii. p. 176, and vol. vi. p. 101.

was made of caoutchouc, with copper to protect it on the side next the ram. A portion of the copper packing having been torn away, a considerable leakage occurred from the southern press when the trough was at the top, and its gate locked to the adjoining gate of the aqueduct. The trough consequently descended, leaving its upper gate suspended above; and, the water flowing out, the southern trough no longer counterbalanced the other. New packing had been inserted at the time of the inspection; but it leaked so much at first that, though the full trough was raised up to the top by two hours' direct pumping into its press from the hydraulic machinery, it was unable, in descending, to raise the empty trough near enough to the top to regain its gate. On a second attempt, however, just before the Author's departure, when the packing had been made tighter by the water-pressure, the empty trough was raised sufficiently high that, by the aid of props built up inside, it was enabled to recover its gate.

During this stoppage of the lift, the traffic had to be passed through the chain of locks, and was consequently delayed. The lift was constructed by the Société des Anciens Établissements Cail; it was opened for traffic in 1887, and has passed a large number of boats, the time of passage being about twenty minutes.

Louvière Lift.—This lift is situated in Belgium, close to the Louvière station on the railway between Mons and Namur, near the centre of the coal and iron industries of that flourishing little country. It is the first of a series of four lifts to be placed on a length of 5 miles of the new Canal du Centre, in course of construction, for connecting the waterways near Mons with the waterways of Brussels, Charleroi, and Liége. The difficulties, hitherto, in the way of connecting the Condé Canal at Mons with the Charleroi and Brussels Canal, have been a difference of level of about 293 feet in the 13 miles to be traversed by the new canal, 217 feet of which have to be surmounted in the last 5 miles, and a great scarcity of water; but these difficulties are being overcome by the construction of four lifts on the steep section of the canal, with rises of from 50½ to 55½ feet, which can be worked with a very small expenditure of water. The lift at Louvière has been constructed as a test of the system: it is situated at the upper extremity of the canal furthest from Mons, so that, though connected with the adjacent Charleroi and Brussels Canal, it at present leads merely into a cul-de-sac below. As, however, the working of the Louvière lift has proved perfectly satisfactory, the other three lifts, each rising 55½ feet, are to be undertaken at once, as well as the completion of the canal, some of the works of which

with the locks and side-ponds, in the section between Mons and Thieu, skirt the railway on the left-hand side from Mons towards Louvière. On the completion of this canal, Mons will be placed in direct communication by water with Brussels, as well as with Charleroi and Liége; and these towns will obtain direct access by water, through the Condé, and other canals, to the north of France and Paris.

The Louvière lift resembles in its main features the Fontinettes lift, for its troughs have nearly the same area (141 feet by 19 feet), and the rams the same diameter (6 feet $6\frac{3}{4}$ inches) (Plate 6, Fig. 1).[1] The difference of level, however, surmounted is $50\frac{1}{2}$ feet, as compared with 43 feet at Fontinettes; and the depth of water in the troughs is 7 feet $10\frac{1}{2}$ inches, in place of $6\frac{1}{2}$ feet, as they were designed to receive vessels of about 400 tons, making the total weight lifted 1,037 tons, instead of 785 tons. The lift was designed by Messrs. Clark, Standfield and Clark, and Mr. Lyonel Clark is the Resident Engineer, as at Fontinettes; but the Contractors were the Société Cockerill of Seraing.

The figures in Appendix II, furnished by Mr. Lyonel Clark, give additional particulars relating to this lift; and a comparison of Appendixes I and II indicate the main differences between this lift and its predecessor in France. The guides at Louvière slide against light wrought-iron lattice towers at the centre and each end of the troughs. These towers support a footway round the top of the lift; and spiral staircases inside the towers give access to the footway from the quay, and to the central cabin at the top, from which the working of the lift is controlled. A system of interlocking prevents the working of the lift till the gates are in place and everything ready, an arrangement which is also in operation at Fontinettes. A wrought-iron aqueduct, crossing over an adjacent high road, connects the upper reach of the canal with the lift. The hydraulic machinery and quarters for the attendants are contained in a building at the side; and the machinery is worked by two turbines with horizontal axes, on the Girard system, turned by the fall of water from the upper reach. The presses are constructed of cast-iron enclosed in continuous coils of weldless steel: their packing is simpler and more efficient than at the Fontinettes lift; and the dryness of the lift-pits indicates the water-tightness at the presses and the lifting-gates. The actual time occupied in raising a trough, as timed by the Author, was two

[1] The illustration is drawn from one of a series of photographic views of the lift taken by Mr. Lyonel Clark.

and a half minutes. A barge can be conveyed from a point on the canal about 100 feet from the lift, placed in the trough, lifted, taken out, and conveyed a similar distance away in nineteen minutes; so that six barges of 360 tons (the size proposed to be accommodated) could be passed through the lift, three each way, in an hour. The lift appeared to work satisfactorily in every respect; and the Author, having stood on one of the troughs while it was being raised, can testify to the regularity and ease of the motion. Altogether, the Louvière lift exhibits a decided improvement on the Fontinettes lift; and the Belgian Government may be congratulated on the boldness with which it has entrusted the working of this important link in the canal system of Belgium to a series of four lifts, which, to judge from the results achieved at La Louvière, appears likely to be fully justified.[1]

Weirs on the Meuse and the Sambre.

A short stay at Namur enabled the Author to visit the weirs on the Meuse above and below that town.

Weirs between Namur and Liége.—All the weirs below Namur are needle weirs, on the Poirée system,[2] furnished with an arrangement, invented by Mr. Kummer, a Belgian engineer, for releasing the needles. The bars along the top of the frames on the upstream side, for supporting the needles, have one extremity hinged to a frame, whilst the other end is held in place by a vertical spindle on the adjacent frame, so formed that by giving it a quarter of a turn the end of the bar is released, and, revolving on its other extremity, sets free the set of needles resting against it,[3] which are subsequently recovered by a rope passing through iron eyes attached to each needle. A long, solid overfall weir, with its masonry sill parallel to the stream, is placed between two bays of the needle weir, situated consequently at two different points of the river, one adjoining the lock, and the other further down stream to the extent of the length of the overfall weir. This overfall is a necessary adjunct to the needle weirs, in order to

[1] Further particulars and illustrations of these lifts are given in Le Génie Civil, vol. vi. p. 101; "Engineering," vol. xl. pp 29, 101, and 103, and vol. xlv. p. 201; "Mittheilungen uber die Hydraulischen Schiffselevatoren," von Carl Fréson, Frankfurt a. M., 1888; and "The Engineer," vol. lxvi. 1888, p. 514, and vol. lxvii. 1889, pp. 28, 76 and 82.

[2] Minutes of Proceedings Inst. C.E., vol. lx. p. 30.

[3] *Ibid.*, vol. lxii. p. 375; and Annales de l'Association des Ingénieurs sortis des Écoles speciales de Gand, vol. ii p. 119.

provide for changes in the discharge of the river, and to prevent a sudden flood from submerging the foot-bridge on the frames of the needle weir before the weir-keeper is able to release the needles. The river is being enlarged for a little distance below Namur to facilitate the passage of floods, which are liable to inundate parts of the town. A new lock, of large dimensions, has accordingly been constructed, on the right bank, at the first weir below Namur; and the site of the old lock is being converted into an extension of the weir. All the weirs on the river between Namur and Liége have been constructed on the above system; and at the weir at Liége two locks have been provided for the navigation, and also a basin at the side, in which vessels can take shelter from floods or floating ice.

Weirs above Namur.—Above Namur, the weirs consist of a combination of the Poirée and Chanoine systems; for whilst needles are used for closing the navigable pass, shutters are placed across the shallower passes.[1] In the earlier weirs on this part of the river, shutters were placed across the whole weir; but the raising of the last shutters proved difficult, and the closing of the weir caused abrupt variations in the water-level. Accordingly, in the later weirs, and in deepening the navigable passes of the existing weirs, needle weirs have been substituted for shutters across the navigable passes. The shutter weirs in these cases, with their large butterfly-valves, serve for regulating the discharge of the river, and for preventing the submergence of the needle weir, and enable a solid overfall to be dispensed with; but, on the other hand, the shutter weirs are more subject to injury than the needle weirs, and are also more costly, when provided with the requisite adjunct of a footbridge on movable frames.

Weir on the Sambre.—The lowest weir on the Sambre, at Namur, just above its confluence with the Meuse, consists of three bays separated by masonry piers; and it is closed by the primitive arrangement of letting down long timber balks horizontally, kept in place at each end by grooves in the piers, which are raised again, for opening the weir, with chains by aid of winches on the piers. The adjacent lock is of very small width, and appears quite inadequate to accommodate properly the traffic on the river.

The Gileppe Reservoir Dam.

Plate 6, Figs. 2 and 3.

Dolhain Station, near the Belgian frontier, is only a short journey from Liége; and the Gileppe dam is only about half an

[1] Minutes of Proceedings Inst. C.E., vol. lx. p. 33.

hour's drive from the station. This masonry dam was constructed in 1867–75 across the deep, narrow, rocky valley of the River Gileppe, to form a reservoir for supplying the cloth manufactories at Verviers with water (Plate 6, Fig. 2). The dam is one of the highest in existence, for it retains a head of water of $147\frac{2}{3}$ feet, being only a few feet lower than the Furens and Villar dams,[1] and somewhat higher than the Vyrnwy dam,[2] the first masonry dam in England, where, though the head of water retained will not exceed 86 feet, the maximum height of the dam exposed to water-pressure amounts to about 132 feet, owing to the depth of the surface of the rock below the upper porous stratum. The dam is a fine piece of masonry work, well executed; but the roadway and footpaths along the top, with a total width of $49\frac{1}{5}$ feet, exhibit a superabundant strength, which is continued all the way down, imposing an unnecessary pressure on the base (Plate 6, Fig. 3). It compares unfavourably in this respect with the Furens dam across the valley d'Enfer in France, which approximates very closely to the theoretical section, having been given a width of $18\frac{3}{4}$ feet at the surface of the reservoir, and a width of 164 feet at the bottom level of the reservoir, in place of the 216 feet width at the base of the Gileppe dam, although the maximum head of water retained at Furens exceeds the head at the Gileppe by $16\frac{1}{3}$ feet. The possibility, however, of raising the Gileppe dam 33 feet higher at some future time was contemplated, in which case its base would approximate to the theoretical width. The dam has been given a convex form towards the reservoir, which adds to its strength; and the masonry has been carried into the solid rock both at the base and sides. A certain amount of infiltration has occurred along the lower portion of the central part of the dam, accompanied with the oozing out of a little of the lime, which has formed a sort of scale on the down-stream face of the dam; but, though this face is wet, its solidity does not appear to have been affected. The dam, as viewed from the valley below, is somewhat dwarfed in appearance by the colossal lion at the top, which affords a deceptive comparison of size.

The reservoir was full of water up to the sills of the by-washes when the Author saw it; and at this level it has an area of $197\frac{1}{2}$ acres, and contains about 16,000,000 cubic yards of water.

[1] Minutes of Proceedings Inst. C.E., vol. lxxi. p. 379.

[2] Sections of the four dams here referred to, drawn to the same scale, are given in the article "Water-Supply" of the Encyclopædia Britannica, 9th Edition, vol. xxiv. p. 407.

Two by-washes, 82 feet wide, formed in the rock beyond each end of the dam, provide for the discharge of the floods of the River Gileppe; and the road is carried over these by-washes on low bridges, as the road is 6½ feet above the sills of the by-washes. The cast-iron conduits for conveying the water-supply have been carried through the solid rock, on each side of the valley, about 250 feet beyond the ends of the dam.[1]

The River Main between Frankfort and Mainz.

Plate 6, Figs. 4 and 5.

Canalization of the River Main.—Till quite recently, the traffic up to Frankfort by water was comparatively inconsiderable, and had to be carried on by small barges; for the longitudinal training works on the left bank, and the cross jetties along the right bank had only secured a depth of 3 feet of water at the low stage of the river. The canalization, however, of the Main from its junction with the Rhine at Mainz up to Frankfort, a distance of about 22 miles, commenced in 1883 and completed in 1886, has given a minimum depth throughout of 6½ feet, enabling vessels to get up to Frankfort, and has thus entirely transformed the navigation of the river. This has been effected by the erection of five locks and weirs, the lowest of which is situated a little above Kostheim, about 2 miles from the mouth of the Main, and the one furthest up stream at Niederrad, 2 miles below Frankfort. These two locks have a lift of 8 feet 10 inches each, and the three intermediate locks have each a lift of 5 feet 11 inches, making the total average rise from the Rhine to Frankfort, at the low stages of the rivers, 35 feet 5 inches (Plate 6, Figs. 4 and 5). The river has also been dredged in several places where deficient in depth; and a rocky reef has been removed from its bed at Frankfort.

The works at the junction of each of the reaches into which the Main has been divided below Frankfort, comprise: (1) a lock on the left bank, constructed in a side cut; (2) a fish-ladder in masonry between the river embankment of the lock and the weir; (3) a needle weir across the main portion of the river, divided into two or more bays by masonry piers; and (4) a pass for rafts of timber, adjoining the right bank, closed by a drum weir.

[1] A full description, with illustrations, of the Gileppe dam is given in the Annuaire de l'Association des Ingénieurs sortis de l'École de Liége, 2nd series, vol. v. p. 281, and vol. vi. pp. 268 and 421; and an abstract of these articles will be found in Minutes of Proceedings Inst. C.E., vol. xlviii. p. 312.

Locks on the River Main.—The locks have been provided with a long approach channel, separated from the main river by an embankment; they are 279 feet long between the gates, affording an available length of 246 feet for vessels; and they are 34½ feet wide. The sills of the locks have been placed 8 feet 2½ inches below the water-level retained by the weirs, although the minimum depth of the river is only 6 feet 7 inches, in order to allow of a further deepening of the bed of the river, in the event of the minimum navigable depth of the Rhine being increased to 8¼ feet, by the erection of a lock and weir between Bingen and St. Goar, where, occasionally, in times of drought, the depth falls to 5 feet. The locks on the Main have been designed to accommodate the steamboats navigating the Rhine, which are 246 feet long, 32⅘ feet broad, and can carry up to 1,300 tons of cargo when the state of the river admits of their maximum draught of 7 feet 10 inches. Vessels of from 700 to 1,000 tons can now go up to Frankfort. Provision has been made, in forming the side channel, to allow for elongating the locks at a future time, by placing a third pair of gates 920 feet lower down, to enable a train of barges with a tug to be locked in one operation. The upper pair of gates of the locks, together with their adjoining side walls and quays, have been raised above flood-level at all the locks except Florsheim, so as to be always under control, and to prevent a rush of water through the lock in flood-time; and the lock-keeper's house, which is placed at the same level, is connected with them by a high embankment, so that he has always access to the upper gates with their machinery.

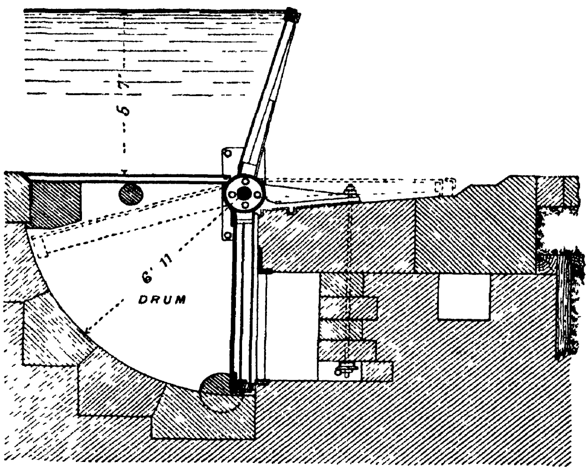
Needle Weirs on the River Main.—These weirs, which stretch right across the river, from the lock on the left bank to the timber pass on the right bank, are divided into bays by masonry piers; and one of these openings in each weir (from 154⅓ feet to 193½ feet in width) serves as the navigable pass for vessels in flood-time, when the lock is submerged and the weir open; and its sill is 10 feet 2 inches below the water-level retained by the weir. The remainder of the weir has its sill 2 feet higher, as it only serves, when open, for the discharge of the flood-waters. The weir at Niederrad, near Frankfort, has four openings,[1] with a total width of 526¼ feet; the weirs at Höchst and at Kostheim have each two equal openings of 193½ feet, giving a total width of 387 feet; the weir at Okriftel consists of two openings of 177⅚ feet, making a total width of 355⅔ feet; and the weir at Flörsheim, in addition to two similar

[1] The openings at the Niederrad weir consist of two bays of 142⅔ feet, one of 154⅓ feet, and one of 87¼ feet in width.

openings, has a third opening of 181¾ feet, affording a total width of about 537½ feet.

These weirs have been constructed on the Poirée system,[1] with iron frames hinged at the bottom, and wooden needles in which the Kummer modifications have been introduced; and, therefore, they are precisely similar to the needle weirs on the Meuse described above. The long overfall weirs, however, which adjoin the needle weirs on the Meuse, have been dispensed with, as the drum weir across the timber pass can be used to regulate a sudden flood till the needles can be released, and also acts as an

Fig. 1.



Drum Weir on the Main.
Scale $\frac{1}{80}$.

overfall for adjusting small variations of level. The leakage also between the needles, aided here and there by their accidental or intended displacement, provides an outflow for the summer discharge of the river.

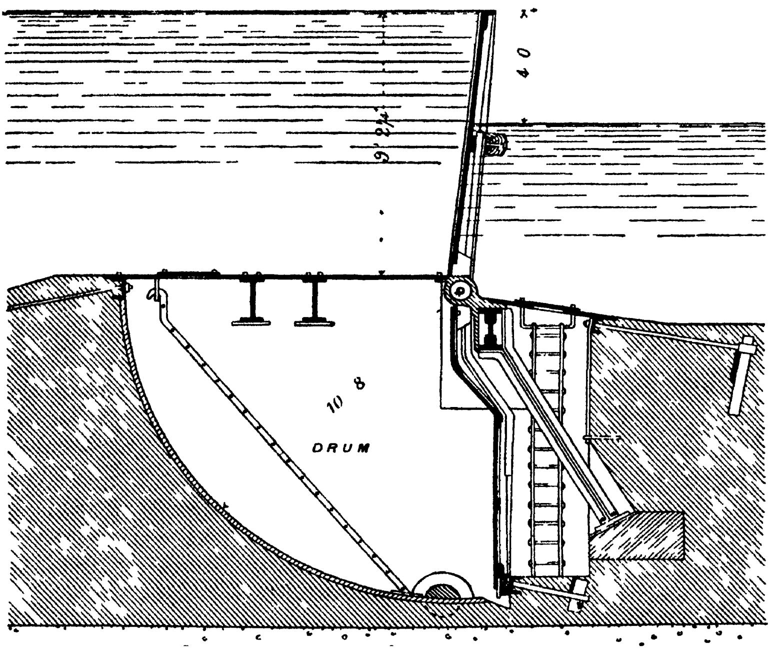
Timber Passes with Drum Weirs.—The timber passes consist of a channel, from 656 feet to 1,312 feet long, and 39⅓ feet wide at the bottom, formed between the right bank and an embankment in the river, and closed at the upper end by a drum weir (Fig. 1). The sill of this weir is 5 feet 7 inches below the water-level maintained by the weir; and the bed of the channel has been formed to a slope

[1] Minutes of Proceedings Inst. C.E., vol. lx. p. 30.

of 1 in 200 down-stream. Timber rafts can at any time be floated through these passes by opening the drum weir, which is about in a line with the needle weir, but separated from it by the embankment.

The drum weir consists of an upper and an under paddle, capable of making a quarter of a revolution on a horizontal axis between the paddles at the level of the sill of the weir. The

FIG. 2



DRUM WEIR ON THE SPREE AT CHARLOTTENBURG

Scale

upper paddle closes the weir, when vertical; and the pressure of the water on the under paddle regulates the working of the weir, by a see-saw arrangement of sluice-gates opening or closing the communication between the drum, in which the under paddle revolves, and the upper and lower reach respectively. The weir is, in fact, precisely similar in principle and action to the drum weirs established by Mr. Desfontaines on the River Marne many years ago, described in the Author's Paper on "Fixed and Movable

Weirs;"[1] but it differs from them in having only a single paddle for closing the weir, $39\frac{1}{3}$ feet wide, stretching right across the opening for the timber pass, instead of consisting of a series of paddles only 4 feet 11 inches wide each. The height, also, of the upper paddle of the drum weirs on the Main has been made 5 feet 7 inches; whereas the upper paddles on the Marne weirs are only 3 feet $7\frac{1}{2}$ inches in height. The drum weirs on the Main, accordingly, mark a distinct extension of the system to larger dimensions; and these weirs had previously been exclusively confined to the Marne.[2]

A still larger drum weir, however, has been erected recently on the River Spree at Charlottenburg (Fig. 2); for the upper paddle, closing the navigable pass, is 32 feet $9\frac{1}{2}$ inches wide, and 9 feet $8\frac{1}{2}$ inches high; the sill of the weir is only $2\frac{1}{4}$ feet above the bed of the river, and the head of water retained is 9 feet $2\frac{1}{4}$ inches.[3]

Cost and results of Canalization of the Main.—The works were carried out by the State at a cost of £275,000, on the understanding that the town of Frankfort would carry out important works for improving the commercial capabilities of the port. Some details of the cost are given in Appendix III. The navigation of the river is free; and no tolls are charged for passing through the locks.

The increased depth of the river, aided by the improvement of the port, has produced a very remarkable development in the trade going up the river to Frankfort; for, whereas the traffic coming up to the port, in the last two years before the carrying out of the works, amounted to only from 10,000 to 11,000 tons, it rose in 1887, the first year after the completion of the works, to 250,000 tons; and it has been estimated that it would reach between 400,000 and 500,000 tons in 1888, having attained 200,000 tons in the first half of the year. The traffic between Frankfort and places above it has not shared in this increase, being unaffected by the improvement of the river, and appears, indeed, to have somewhat

[1] Minutes of Proceedings Inst. C.E., vol. lx. pp. 36 and 58, and Plate 3, Figs. 3 and 4.

[2] Additional details of these works will be found in "Zeitschrift fur Bauwesen," Berlin, 1888. Text, p. 19, and Atlas, Plates 14 to 17; "Die Canalisirung des Mains von Frankfurt a. M. bis zum Rhein;" and Annales des Ponts et Chaussées, 6th series, vol. xv. 1888, p. 931. The works have also been briefly referred to in Minutes of Proceedings Inst. C.E., vol. lxxxviii. p. 501, and vol. xcii. p. 444.

[3] "Zeitschrift für Bauwesen," Berlin, 1886. Text, p. 338, and Atlas, Plates 31 and 32.

decreased; but the exports from Frankfort, both up and down the river, though much smaller than the imports, have also experienced a remarkable increase since the completion of the works, for they rose from 1,900 tons in 1885 to 7,100 tons in 1886, and to 46,600 tons in 1887. This wonderful rise in the river traffic is the more satisfactory as it is not due to a diversion of trade from the railways to the river, brought about by the expenditure of public money for which no charges are levied, for the railways have also shared in the increase of traffic. Thus the increase of traffic on the river has been accompanied by an augmentation of 36 per cent. in the railway traffic, showing that, under certain conditions, the improvement of inland waterways, even when in a position to enter into competition with railways, may so develop the trade of a district that the railways largely benefit by the increase of prosperity effected by their apparent rivals.

Port of Frankfort.

Plate 6, Fig. 6.

The port of Frankfort consists of quays along both banks of the river through the town, and of a haven for vessels to take refuge in from floods and floating ice, which is also used for commercial purposes. The formation of the haven, and an extension of the quays have been carried out by the town of Frankfort, in fulfilment of an agreement entered into when the State undertook the improvement of the Main (Plate 6, Fig. 6).

Quays.—The quays extend through the town, almost continuously, along each bank of the Main, above the disused Main-Neckar railway bridge crossing the river beyond the lower end of the town, and have a total length of nearly 3 miles. The recent extensions consist of 492 lineal yards of the Obermain quay and 547 yards of the Untermain quay on the right bank, and 558 yards of the Deutschherrn quay on the left bank, at a total cost of £27,590. The quays on the right bank adjoining the town are provided with railway accommodation throughout, with additional sidings in some places; but the quays on the left bank are not in communication with the railways, with the exception of the new quay for heavy goods below the Main-Neckar bridge. This new quay, extending along the left bank of the Main between the Main-Neckar and Staats railway bridges, 1,160 yards long, is mainly used for a coal depôt: it is provided with sidings alongside the river, with travelling hydraulic cranes, with overhead tram-roads

on which small trollies run for distributing the coal, and with sidings on the land side of the pens, in which the coal is stored, communicating with the railways.

Haven at Frankfort.—The haven has been formed on the right bank of the Main, just below the Main-Neckar bridge, by an embankment, about 580 yards long, in the river, parallel to the shore, and raised above flood-level, thus enclosing a basin, 1,740 feet long and 246 feet wide, permanently open only at its lower end for the entrance of vessels, which are sheltered in it during high floods, and against floating ice in the winter (Plate 6, Fig. 6). It has been excavated to a depth of 9 feet 2 inches below the lowest water-level, so that vessels may remain afloat in it when the Niederrad weir is open; and it has a depth of 16¾ feet below the ordinary water-level retained by the river. An entrance has been formed at the upper end for facilitating traffic in ordinary times, furnished with a pair of gates which can be closed when required. Quays have been formed round the haven, 580 yards in length along the embankment, and 908 yards along the shore, which have been provided with sidings: and one large warehouse has been erected, together with some sheds, space being left for the erection of four more warehouses when required. The quay along the shore has been furnished with hydraulic travelling cranes, capstans, and traversers for shifting the wagons. A telescopic grain-elevator, for lifting the grain from the hold of a vessel and discharging it into sacks, has been placed on the quay, and can be moved along rails the whole length of the quay between the warehouses and the haven. The warehouse, having six floors and a basement, is separated into three blocks: it has a total length of 328 feet, and a width of 87 feet. It is provided with lifts; and a large grain elevator projects over the quay, from the centre of the front of the building, by which grain can be raised direct from the vessel, and can then be distributed to various parts of the warehouse by aid of travelling bands and shoots. These machines are all worked by hydraulic power; and provision has been made for using the same power for working the gates closing the upper entrance to the basin, and the swing-bridge across the entrance connecting the lines of way on the embankment with the mainland. Sidings on the far side of the warehouse communicate both with the lines along the quays of the right bank, and also with the main lines, and are connected with the sidings in front of the warehouses by traversers.

The cost of these works, together with the quays, sidings, and depôts on the opposite bank, amounted to £315,800; so that, with

the extension of the quays above, the town has spent nearly £350,000 in the improvement of the port. The works of the haven and quays had, since 1878, been carried out by Mr. W. H. Lindley, M. Inst. C.E., Engineer to the town of Frankfort.[1] The works on the right bank were completed in 1887, and those on the left bank in 1888.

The success which has attended the works of improvement of the Main, and of the port of Frankfort, must be in a great measure attributed to the position occupied by Frankfort, which is now the eastern terminus of the river traffic along the Rhine. The River Main above Frankfort, from which the town formerly derived the greater portion of its traffic, is in communication with the Danube through the River Regnitz, a tributary of the Main, and the Main-Danube canal which joins the River Altmühl, a tributary of the Danube; but the depth is inadequate between Frankfort and Bamberg, on the Regnitz; and the remainder of the route is impeded by numerous small locks and a deficiency of water in the canal, and by a low water-level or a rapid current in the rivers as far as Ratisbon on the Danube. The traffic, accordingly, along this route is very small; but these impediments, though stopping the extension of inland navigation in this direction, have the advantage for Frankfort of leaving it at the head of the river trade towards the east.

New Passenger Station at Frankfort.—Whilst the river and port have been improved, the railway companies have not remained idle; for the Author, on his arrival at Frankfort, in August, 1888, entered the new station there on the day of its opening. This central station has replaced the three small terminal stations of the Main-Weser, the Taunus, and the Main-Neckar lines (Plate 6, Fig. 6), and has also been placed in communication with the lines to the east of the town. The covered portion is 610 feet long and 551 feet broad, with a glazed arched roof in three spans, resembling three Cannon Street stations side by side, with iron columns for the intermediate supports. The station receives eighteen lines of way, and has a grand central entrance-hall containing the various booking-offices, handsome large side passages leading from the hall to the various waiting-rooms, refreshment-rooms, &c.; and a wide space beyond, between the offices and the ends of the lines, leads to the several platforms. The whole building is very tastefully designed and decorated; and the main station and its approach lines are illuminated at night by electric arc-lights; whilst the offices,

[1] Full details of these works, with illustrations, are given in "Beschreibung der Frankfurter Hafenanlage," by W. H. Lindley, 1888.

rooms, and passages are lighted with glow-lamps. Lifts have been erected at suitable places on the platforms; so that the luggage, which is conveyed along underground passages, can be raised to the vans, or lowered and removed, without interfering with the passengers or blocking up the platforms. The electric lighting and the working of the lifts are effected by the aid of hydraulic machinery, situated in a handsome building, surmounted by a dome, on the right bank of the Main near the Niederrad weir. Steam-engines in an adjacent building generate the hydraulic pressure, which is stored by two large square accumulators, from whence it is transmitted to the dynamos, for producing the electricity, which are placed nearer the station. The station and accessory works cost altogether £1,750,000; but a considerable portion of this expenditure will be repaid by the sale of the lands previously occupied by the stations and railways, which penetrated further into the town. The Author considers that the station, both in its design, general arrangements, and details, is an excellent model of what a station ought to be, with the exception of the platforms, which being, according to the usual continental plan, nearly on the level of the rails, render the getting into and out of the high carriages so inconvenient. Also vehicles are not admitted into the station; but this inconvenience is to a great extent obviated by the arrangements for the luggage.

Sewage Disposal Works at Frankfort. The town of Frankfort no longer pollutes its river with its sewage; for works have been constructed by Mr. W. H. Lindley, on the left bank of the Main, about a mile below Niederrad weir, for separating the solids and purifying the effluent. The sewage on its arrival is mixed with alum and lime; and, being passed through a series of underground tanks, the solids are precipitated and settle down, and the liquid portion is clarified. The purified effluent is then restored to the river; and the sludge is pumped up into two open tanks above ground, and is either used upon the adjacent land, or prepared for manure. The sewering of the town was commenced in 1867; the greatest progress was made between 1872 and 1878; and the works were completed in 1886, when a detailed account was published by Mr. Lindley.[1] The works have had a remarkable effect on the health of the town; for whereas, up to 1874, typhus was very prevalent in most years, the number of cases diminished rapidly in the next three years; and the maximum percentage since 1875 has never reached the minimum of the previous twenty-five years.

[1] "Beschreibung der Enterwässerungs-Anlagen der Stadt Frankfurt-am-Main" von Stadtbaurath, W. H. Lindley, 1886.

Port of

Plate 6, Fig. 7.

The Hessische Ludwigs Railway Company, owning the line between Mainz and Frankfort, has not quietly awaited the possible diversion of its traffic by the canalization of the Main, but has hastened to improve the port of Gustavsburg on the right bank of the Rhine, opposite Mainz, just above the confluence of the Main (Plate 6, Fig. 7). New basins have been constructed, with railway sidings alongside the quays which have been amply provided with cranes, sheds, and other appliances for facilitating trade. The quays have been formed of timber platforms resting upon piles driven into the pitched slopes surrounding the basins, and have been so laid out as to provide a considerable length of quays in proportion to the water area. The fan-like form of the sidings, also, is very advantageous for the traffic. The railway company is endeavouring, by these increased facilities, to forestall some of the traffic which might otherwise go up to Frankfort by water; and there appears to be a good amount of trade in the port.

Port of Mainz.

Plate 6, Fig. 8.

Another port has been established at Mainz, a little lower down the Rhine than Gustavsburg, on the left bank just below the town, with a basin surrounded by quay walls, and a haven of refuge for vessels (Plate 6, Fig. 8). A large warehouse, in the form of a square, with a courtyard in the centre, has been built on a quay projecting into one end of the basin, so that it is surrounded by water on three sides. This warehouse has wine vaults in the basement, and several floors above; and side passages along each floor enable any division to be reached without passing through the others. Turrets, at each of the internal corners, contain winding staircases of communication to the several floors. The warehouse is furnished with lifts, cranes, and movable jiggers, worked by hydraulic machinery. It is a handsome building, though without undue ornamentation; and two smaller warehouses face it on either side of the basin. The extension of the river bank with quay walls in front, the construction of the basin, and the formation of the haven, cost altogether £380,000; and the warehouses, with the railway sidings on the quays, cost £65,000.

The depth of the Rhine has been improved along a shallow portion between Mainz and Bingen, by training works between Eltville and Oestrich, regulating and restricting the channel along each side of an island, and for some distance below, with longitudinal training works commenced in 1886.[1] The direction, as well as the depth, of the navigation channel has been thereby improved; and this reach is no longer an impediment to vessels.

Port of Mannheim.

Plate 6, Figs. 9 and 10.

Mannheim possesses the special importance of being at the southern limit of the large navigation up the Rhine, and therefore holds the position as regards the southern districts which Frankfort has endeavoured to secure towards the east. It is, moreover, well situated at the junction of the Rhine and the Neckar, affording it a long line of easily accessible water frontage along both rivers; and it possesses excellent railway communication with the interior. The course of the Rhine has been altered, at its junction with the Neckar, by cutting off a sharp bend, and training the prolonged channel of the Neckar to join the new channel of the Rhine, thus improving the course of the Rhine and the lines of confluence of the two rivers, and providing a large space between the old and new channel of the Rhine for the formation of basins and quays (Plate 6, Fig. 9). The accommodation for vessels provided by the port is indicated on the plan (Plate 6, Fig. 10), from which it will be seen that some basins between the two rivers supplement the river frontages for the purposes of trade, and, together with the old channel of the Rhine, afford a refuge for vessels from floods and ice. Railway accommodation is provided along all the quays; and ample sidings have been laid along the quays surrounding the Mühlau basin, and on the left bank of the Neckar. Numerous warehouses and sheds have been erected on the quays; and some of the warehouses are provided with grain elevators and travelling bands, as well as with other machinery for transporting and storing goods. The total length of wharfs and quays in the port, and along the Rhine and the Neckar, amounts to $4\frac{1}{3}$ miles.[2]

[1] Minutes of Proceedings Inst. C.E., vol. xcii. p. 445.

[2] Additional details about the port will be found in "Die Mannheimer Hafenanlagen, 1886," and statistics relating to its trade in "Jahresbericht der Handelskammer für den Kreis Mannheim für das Jahr 1887."

The training of the Neckar was commenced in 1864, and completed in 1873; the Mühlau basin and the central goods depôt alongside were commenced in 1870; and the Junction Canal, connecting the Mühlau basin with the Neckar, was constructed in 1875–78. Access to the upper end of the Mühlau basin is afforded by a lock, whose chamber is 315 feet long, and 34½ feet wide; and the iron lock-gates close this entrance against floods and ice. A sum of about £965,000 has been spent in the last twenty-four years upon the works of the port. The training of the Neckar cost £88,700; the Muhlau basin and central goods depôt, £420,000; the Junction Canal, £52,100; the works along the river bank, £86,900; the sorting sidings, £108,100; and the extension of quays, new basins, and bridge, £120,000.

The traffic of the port of Mannheim has increased more rapidly than that of any of the other ports on the Rhine in recent years, having risen from 252,000 tons in 1856 to 583,000 tons in 1876, and to 1,796,000 tons in 1886. It is only exceeded by Ruhrort, below Dusseldorf, which, though having a much smaller import trade, has a much larger export trade than Mannheim. The joint trade, however, of Mannheim and Ludwigshafen, on the opposite bank, of 2,443,000 tons in 1886, very nearly equalled the 2,472,000 tons of Ruhrort; and as the trade of Mannheim has been increasing still more rapidly than the trade of Ruhrort in recent years, it is probable that Mannheim and Ludwigshafen together will soon be decidedly in advance of all the other ports on the Rhine. The prosperity of the port of Mannheim exemplifies, in a remarkable manner, the advantages of extending deep-water communication as far into the interior of a country as practicable; and the rapid growth of the river traffic, both at Mannheim and Frankfort, indicates the important position held by those ports which are situated at the extreme limits of large navigations.

Concluding Remarks.—In visiting the works above described, the Author was struck with the great industrial activity of Belgium, and the rapid development of inland navigation in Germany; the solicitude which the Belgian and German governments have exhibited for improving and extending the water-ways of their countries, and the eagerness with which the local authorities second these improvements, by enlarging their ports, and providing them with the most modern mechanical appliances for facilitating trade.

More attention appears to be paid on the Continent to the architectural features of buildings devoted to trade purposes, so that warehouses, and even engine-houses and buildings for hydraulic machinery, exhibit some pretensions to adornment. These advan-

tages, moreover, appear to be attained without undue expenditure by authorities whose whole object is the promotion of trade.

The Author considers that visits abroad indicate that English engineers cannot afford to relax their exertions in the way of progress, if they are to keep in advance of their professional brethren on the Continent; and that the extension of water-communication gives facilities for economical traffic, which English merchants must not neglect if they desire to retain the ascendancy of English trade.

The Paper is accompanied by several small scale drawings, from which Plate 6 and the Figs. in the text have been engraved.

APPENDIXES.

APPENDIX I.—Fontinettes Lift, Neuffossé Canal, France.

Trough:—	Metres.		Feet. Ins.
Length	39·50	=	129 7
Breadth	5·60	=	18 4½
Depth of water	2·00	=	6 6¾
Press; copper internal cylinder, with exterior weldless steel coils:—	Millimetres.		Inches.
Thickness of copper cylinder	3	=	0·118
" external steel coils	55	=	2·165
	Metres.		Feet. Ins.
Length of press	14·987	=	49 2
" stroke (height of lift)	13·13	=	43 1
	Atmos.		Lbs. per sq. in.
Pressure on press	25	=	442·5
Ram.—	Millimetres.		Inches.
Thickness of cast-iron	60	=	2·362
	Metres.		Feet. Ins.
External diameter	2·00	=	6 6¾
Total weight lifted, including trough, water, and ram	785 tons		
	Atmos.		Lbs. per sq. in.
equivalent to a pressure of	25	=	442·5
The contents of one stroke in water	41¼ tons		
	Centimetres.		Inches.
equivalent to a surcharge on the trough of	20	=	8
Actual surcharge used	88 tons		
	Millimetres.		Inches.
equivalent to a depth of water of	400	=	16
Size of boats lifted	250 tons		
Actual time of lift	5 to 7 minutes		
Total time of passing one boat up and one boat down	20 minutes.		

APPENDIX II.—Louvière Lift, Canal du Centre, Belgium

Trough:—	Metres.		Feet. Ins.
Length	43·000	=	141 1
Breadth	5·800	=	19 0¼
Depth	3·250	=	10 8
Draught of water	2·400	=	7 10½
Breadth of free passage	5·200	=	17 0¾
Headroom under gates	4·250	=	13 11⅜
Length of centre guides	7·768	=	25 5¾
" end "	3·450	=	11 3¾
Ram; cast-iron:—			
Diameter	2·000	=	6 6¾
Thickness	0·075	=	0 3
Length	19·440	=	63 9½

Press; cast-iron, hooped with continuous steel weldless coils:—

	Metres.		Feet.	Ins.
Internal diameter	[illegible]	=	[illegible]	[illegible]
Thickness of cast-iron core	0·100	=	0	4
,, steel coils	0·050	=	0	2
Length of press	19·590	=	64	3¼
Stroke	15·397	=	50	6¼
	Atmos.		Lbs. per sq. in.	
Working pressure	32	=	469	

Two turbines and four pumps to furnish collectively 24 cubic metres (5,275 gallons) of water per hour under a pressure of 40 atmospheres = 569 lbs. per square inch.

Accumulator:—

	Metres.		Feet.	Ins.
Ram, diameter	0·500	=	1	7¾
Stroke	7·700	=	25	3

equivalent to 40 centimetres stroke of great rams.

Weight of trough, water, and ram . . . . 1,037 tons.

	Atmos.		Lbs. per sq. in.
equivalent to a pressure of	32	=	469

Weight of water in trough (depth 2·40 metres) . . . . 598 tons.
Normal working surcharge, 0·25 metre . . . . . 10 inches = 62 ,,
Stroke of press equivalent to . . . . 48½ tons of water.
Size of vessels lifted . . . . 400 tons.
Actual time of lift . . . . 2½ minutes.
Total time, including entering and departure of barge . . . . 15 ,,
this comprises the lifting of one boat and lowering of another = 800 tons passed.

APPENDIX III.—Canalization of the River Main.

Cost of Weirs and Locks.

Name.	Land.	Needle Weir, Timber Pass, and Fish Pass (exclusive of Ironwork).	Lock.	Approach Channel to Lock.	Buildings for Attendants.	Ironwork for Needle and Drum Weirs.	Total Cost.
	£.	£.	£.	£.	£.	£.	£.
Frankfort .	9,350	22,715	14,455	14,995	2,150	1,615	65,280
Höchst . .	1,450	16,165	16,323	9,050	905	1,199	45,092
Okriftel. .	1,040	13,715	15,141	7,300	1,000	1,106	39,302
Florsheim .	2,950	18,250	13,380	8,176	830	1,627	45,213
Kostheim .	1,010	16,783	14,465	9,630	1,022	1,220	44,130
Totals .	15,800	87,628	73,764	49,151	5,907	6,767	239,017
Averages	3,160	17,526	14,753	9,830	1,181	1,353	47,803

Discussion.

B. Sir G. B. Bruce, President, remarked that the Author had made extremely good use of his opportunities when abroad, and the members were much indebted to him for having put his information into shape, and laid before the Institution such a valuable *résumé* of what he had seen.

n- Mr. L. F. Vernon-Harcourt said that, through the kindness of Mr. Boulé, *Ingenieur en chef* of one of the sections of the Seine, and a delegate of the French Government to the Congress at Frankfort, he had the opportunity of visiting the two lifts in company with the French and Belgian engineers of those lifts, and he was struck with the difference in the views of those two gentlemen. The French engineer of the Fontinettes lift seemed rather afraid of trusting the navigation to it, and thought it fortunate that it was supplemented by the original chain of locks; whereas the Belgian engineer was perfectly satisfied with Louvière lift, and thought that the new canal, which would depend for its traffic upon the four lifts (three of which remained to be constructed) would certainly be a success. The Charlottenburg drum weir (Fig. 2) was the largest, he believed, in existence; and he had placed on the table detailed drawings of the weir, sent by the engineer of the work.[1] He had not had the opportunity of getting the details of the new bridges which traversed the Main near Frankfort in connection with the new station, but they appeared to him to be remarkably light in construction, when compared with the Putney girder-bridge across the Thames, now in course of construction. The cause of it, he imagined, was that German engineers gave a greater depth to girders than was usual in England; and it was known, from a Paper by Mr. Max am Ende,[2] that the most economical form of bridge was that in which the depth bore a much larger proportion to the span than was customary in this country.

1 Coode. Sir John Coode, Vice President, was glad the Author dwelt at length upon the great advantages to be obtained by an extension of inland navigation, a question which the commercial community in this country might well take to heart, there being ample scope for such extension. He had hoped that some allusion would

[1] These drawings are in the Library of the Institution.

[2] Minutes of Proceedings Inst. C E., vol. lxiv. p. 270.

have been made to an arrangement on the Grand Western Canal on the right-hand side of the Bristol and Exeter Railway, between Taunton and Wellington, an arrangement which appeared to him to be the germ of what had been done at Fontinettes and Louvière. It was a balance lift, having an ascending and a descending trough. The circumstances were somewhat different. In the one case gravity did the whole of the work, but in the other hydraulic power was brought to bear. Perhaps the Author was not aware of the arrangement on the Grand Western Canal, as it was almost a matter of ancient history. An account of it would be found with three illustrated plates, in a Paper by Mr. James Green, the originator of the proposal.[1] This lift rose 46 feet, nearly as much as the higher of the two lifts referred to in the Paper. The boats, which were much lighter, were ordinary canal boats, but they were passed, one up and one down, in three minutes. Mr. Green had truly said that the same method would apply to greater heights, and a larger tonnage. With regard to the advantages of an extension of water communication, he had been, within the last few days, much struck with a statement that in Germany in 1887, there passed, by internal water communication, no less than 17,568,000 tons, being an increase over the average of the previous five years of 22¾ per cent. in the merchandise conveyed, and 24½ per cent. in the tonnage of the vessels employed. He thought that was a very significant fact, and one which the commercial community at home might seriously consider. The Paper under discussion was one which young engineers going abroad should imitate. They might not be able to get sufficient information with regard to any one particular work, but they might, like the Author, judiciously group a number of works together, and bring them before the Institution. The ports of Gustavsburg and Mannheim deserved careful study. They were instances in which very great advantage had been taken of the physical features of the ground. Mannheim had been exceedingly well laid out. The Mühlau basin might appear to be narrow, only 320 feet wide, and when two barges were lying abreast on each side there might be a difficulty in turning; but that had been provided for, because there was through communication, and the mode of linking up the rivers was well devised and interesting.

Sir John Co

Mr. A. GILES, M.P., Vice President, said that if young English engineers were gifted with the same industry that the Author

Mr. Gile

[1] Transactions Inst. C.E., vol. ii (1838), p. 185.

Mr. Giles. had exhibited, there would be no occasion for the remark in the Paper "that English engineers cannot afford to relax their exertions in the way of progress, if they are to keep in advance of their professional brethren on the Continent." He was glad, however, to find that they were indebted to English engineers for the designs of the lifts described in the Paper. He thought that, as the works were new, of considerable magnitude, and of some risk, it was better to follow the French engineer, and leave the old system of locks still in force in case of accident, instead of, according to the Belgian engineer, trusting entirely to the new works. It was like leaving gas-lamps as a stand-by when putting up electric lights. He was glad that the works at Frankfort were due to the genius of the English engineers, Mr. W. Lindley and his son, Mr. W. H. Lindley, the former of whom was an old pupil of Mr. Giles's father. He had done good work, both at Hamburg and at Frankfort. The English Government might well take a hint from the authorities of Frankfort and of other ports in helping public works more than they did. Public works in England were mostly done by private subscription and joint-stock enterprise. Many harbours of refuge, fishing ports, and other works were greatly needed; but no assistance could be obtained from the British Government. Efforts had been made over and over again to impress upon the Chancellor of the Exchequer the necessity of providing money for such objects, but without success.

Mr. Lloyd. Mr. E. J. LLOYD thought that some further information should be given as to the amount of economy that would result from the works described in the Paper. In England, as Mr. Giles had stated, such works were carried out by joint-stock enterprise, and the promoters were therefore not in a position to disregard the question of cost. He believed the Anderton lift had never been a commercial success, the reason being that it was never fully occupied. If some information could be given as to the cost of construction and working, and the tonnage capacity of the large lifts referred to by the Author, it would be very useful to the members. It was a matter of great importance, because if the inland canals in England were not enlarged, railway competition would probably render them to a certain extent ineffective.

Mr. Barry. Mr. J. WOLFE BARRY said that caution should be exercised in dealing with generalities, and it ought not to be too readily concluded that because inland navigation was of great utility on the Continent, it would be of equal utility in England. The experience of England up to now was certainly the other way. It had

been lately his duty in Ireland to inspect some important works of inland navigation made by the Government, who were more disposed to assist public works in Ireland than similar works in England. He had visited the very large and well-designed works for the canalization of the River Shannon. The whole traffic of the upper Shannon above Athlone produced £30 a year in gross tolls, while the cost of the works could not have been less than £150,000. Another Irish canal, from which great things had been expected, not only was not paying anything on the capital expended, but it was not even paying its working expenses. As to canal traffic in England, it should be remembered that it must compete with perhaps the most perfect system of railway communication in the world; that the railway companies had their ramifications extending to every town, and that the speed with which goods were conveyed by them compared most favourably with the *petite vitesse* on the Continent. The trader found that speed in the transmission of his goods meant the continuous employment of his capital, increasing his turn-over, and he could not afford the delays of English canal navigation. It might be said that many of the canals had fallen into the hands of railway companies who did not wish to work them for the benefit of the English market. There might be some truth in that in some instances, but in other cases he was certain that it was not so. The reason, he believed, why traffic was diverted from inland navigation in this country was the great facility of collection and delivery of goods by the railways, the inevitable delays of water traffic, and the want of facilities of collection and delivery, such as those which were possessed by the great goods-carrying railway companies. He could well imagine that on the Continent the condition of affairs might be different. There was a very long water traffic to be dealt with, and in such a case the inconveniences to which he had alluded were perhaps not so important as in the case of short journeys, in a small country like England. Engineers should, he thought, be very cautious before coming to the conclusion that there should be a great enlargement of English canals, and that it would be remunerative or of great utility. He knew that it was now the fashion to say so; but he himself doubted whether there was much truth in the idea. Certainly, so far as he had been able to form a judgment, it did not commend itself to his mind as being a thing that would be profitable to investors or convenient to the general traders of the country. Mr. Ba

Mr. H. J. Marten thought there was a smatch of railways, and railways only, about the observations just enunciated. He was Mr. Mart

Marten. professionally interested in a considerable number of inland navigations, principally in England, and he did not take so gloomy a view of their future as that presented by the previous speaker. There had no doubt been cases of failure, where, as in Ireland, large outlays had been made on waterways without due consideration of the sources of probable traffic, and where local enterprise, especially of that description which resulted in the development of a large amount of heavy goods traffic, was at a low ebb. Just as large outlays might, in some cases, have been incurred in constructing unnecessary, and consequently unprofitable, railways. He had found that, where there was a good and well-managed waterway, it could always hold its own, both in time and cost of carriage, in competition with railway-borne heavy goods traffic. Everything, however, depended upon the waterway being in good travelling condition, and upon its having a sectional area and being of a gauge suitable for the traffic to be carried along it. Almost all the canals for conducting the inland navigation of this country needed improvement. As a rule, they were much too small, many of them, in fact, being practically mere ditches. Provision was required for the passage of larger boats, to be propelled by steam or some other cheap motor, instead of by animal power such as horses, donkeys, &c. The existing boats were, in most cases, too small to carry their own propelling machinery with material advantage as regarded cost of transit, the weight of the machinery being in many cases from 20 to 25 per cent. of their cargo-carrying capacity, and consequently displacing that amount of profit-producing tonnage. This might be remedied by enlarging the locks, so as to pass trains consisting of three or four boats at one lockage, whereby, say in the case of one cargo-carrying steam-boat hauling a train of three ordinary canal-boats, the weight of the propelling machinery might be reduced to under 5 per cent. of the weight of the cargo, instead of bearing the large proportion named above. With a larger sectional area of waterway in proportion to the enlarged size of boat;—with the banks "wash," or "deep-walled" on either side of the canal, so as to reduce both the frictional resistance of the displaced water when passing to the rear, and the head of water in front of the boat;—with a proper bottom width and depth under the keels of the loaded boats, so as to enable them to travel and steer well;—by doing away with all the old-fashioned narrow bridge holes through which the traffic now had to be strained, and which were as objectionable on a canal as a single-line neck would be every few hundred yards on a main-line railway;—by en-

larging the locks so as to pass trains of boats at one lockage;— Mr. Ma and by using lifts in certain cases where circumstances might render them applicable, he was satisfied that the inland water-communications of this country would more than hold their own, and that wherever there was sufficient traffic between any given points to support a railway, there would also be sufficient to maintain a well-regulated and well-appointed water-communication in profitable existence. With reference to the observation of Sir John Coode, to the effect that the total water-borne traffic of Germany was 17,568,000 tons in a year, he might state that there was a canal in the central mineral plateau of England, only about 150 miles in length, but principally on one level, the traffic upon which was upwards of 8,000,000 tons a year, or more than half the whole water-borne traffic of Germany. In his opinion the most important fact mentioned in the Paper, and one which materially bore upon Mr. Barry's observations, was that, in the two years since their completion, the improvements on the river Main had resulted, not only in a fortyfold increase of water-borne traffic, but that in the same time the traffic upon the competing railway systems on either side of the river had increased upwards of 36 per cent. In England, the fear had been frequently expressed that any increase of traffic in an improved canal could only be obtained by depriving a competing railway of a quantity of traffic equal to the increase on the canal. Assuming, however, the facts mentioned to be correct, they went far to remove that impression, and he felt much indebted to the Author for bringing them out. Mr. Marten's own view was, and always had been, that railways would be benefited by improved water-communication, because if heavy raw material could be cheaply conveyed by water to any manufacturing centre, railways would have the benefit of conveying from that centre the lighter goods manufactured by means of the cheap water-borne raw materials, and which light goods, requiring quick despatch, and being of a higher class, would yield enhanced and more remunerative rates to the railway companies than the low class and low-rated raw material. He was of opinion that the County Councils, upon whom now devolved the control and management of the main roads, would also be shortly looking into the question of improving the water-communications within their respective jurisdictions. So long as the County Councils did not trench upon the business of carriers, and confined themselves to toll-taking only, there did not appear to be any valid reason why the waterways should not be under their control and management, just as the macadamized roads were now. There were some precedents for

Marten. this course, and he hoped and fully anticipated that, in the near future, the principle would receive further exemplification, as he was satisfied the manufacturing prosperity of many inland districts depended upon improved water-communication.

. Clark. Mr. LYONEL CLARK said that a question had been asked with regard to the cost of the lifts. The only comparison necessary was between the cost of a hydraulic lift and the expenditure that would be entailed for locks to replace them. The mere fact that a certain lift cost a certain sum could not be of much interest, unless the particular style of work was known. Fortunately, with the Louvière lift, the canal comprised several locks having the maximum fall which was found by the Belgian engineers to give the best results, about 16 or 17 feet. Three such locks would be required to compensate for one of the lifts having a rise of 50 feet; and the difference in price would be in favour of the lift. The cost of the lift was 1,250,000 francs (£50,000); and the cost of the three locks would be about 1,500,000 francs (£60,000). The price of the lift might seem excessive, but it was Government work, and no doubt many engineers would say that Government work was not the cheapest. The exact cost of passing boats through was, of course, rather difficult to estimate. It must depend entirely upon the boats. The lift could pass 7,000,000 tons a year, and that was a great deal more than any single lock of 17 feet on the same canal could do. It was quicker to get two boats through, one up and one down, than to get a single boat through an ordinary lock. Reference had been made to a canal in the Midlands passing 8,000,000 tons a year; but that canal was on a level. He knew of no canal containing locks that would pass that amount of tonnage in a year. The lifts were not only cheaper, but quicker in operation. The average time of passing two barges of 450 tons, one up and another down, was only twenty minutes; so that 7,000,000 or 8,000,000 tons could be easily passed through in a year. The lifts mentioned by Sir John Coode were for boats of 30 tons, and there was no trouble in passing them over pulleys by means of chains; but he did not think there were many engineers who would care to take 1,100 tons up 50 feet in three and a half minutes by chains. It would be a great risk. That was why hydraulic power came to be applied to the lifts. In the Anderton lift, the first in England, it was not found practicable to use chains of that sort; and therefore Mr. Edwin Clark was called on to devise some form of hydraulic lift, and that form had been adopted for the lifts under discussion. They varied very little from the Anderton

lift which had been at work fourteen years. The fact that the latter did not pay did not militate against its engineering advantages. A canal in Ireland might not pay now, but that was no reason why a canal in England should not pay. He believed that it would be one of the greatest possible advantages to England to have a thoroughly good water navigation, capable of taking heavy goods, leaving the railways to do their proper work in the quick transit of lighter goods. Mr. Ch

Professor W. C. UNWIN thought that the account which the Author had given of the dams was likely to convey an erroneous impression. To say that the Gileppe dam compared unfavourably with the Furens and the Villar dams was to convey a wrong impression; for there was an enormous difference between the amount of masonry in those dams. Some years ago he had abstracted for the Proceedings[1] a Paper from the "Civilingenieur" in which a careful comparison was made. From this it appeared that in the section of the Furens dam, down to a depth of 115 feet, there were 4,500 square feet of masonry; in the Villar dam to the same level, 4,800 feet; and in the Gileppe dam no less than 12,500 feet—at least two and a half times the amount of the others. The Furens and the Villar dams still stood, and he could not see why two and a half times as much masonry should be needed to stand the same water-pressure at Gileppe. All those dams were now, for engineering works, of respectable antiquity, a full account of the Gileppe dam having been published as long ago as 1877. It appeared to have occurred to the engineer of the Gileppe dam, that the right way to proceed was first to design what the Author had called the theoretical section (as to which no two engineers were agreed), then to design the section of a trapezoidal dam, and then to strike an average between the two. That being so, he did not think the Gileppe dam was a model to be held up for admiration; because, it should be remembered, in a structure of that kind adding masonry at random was as likely to weaken the structure as to strengthen it. The Author had referred to the water percolating through that enormous mass of masonry, and making a scale on the down-stream face. Professor Unwin had a piece of that scale in his pocket, and it was of a rather substantial kind. The fact was that for a large part of the area of the down-stream face, the dam, up to a defined horizontal line, was covered with stalactite an inch or two thick, formed by lime washed through the whole body of masonry by percolation. Professor Unwin.

[1] Minutes of Proceedings Inst. C E., vol. lvi. p. 337.

L. F. Vernon-Harcourt. Mr. L. F. Vernon-Harcourt, in reply, said that it would be difficult to satisfy the conflicting views expressed with regard to the works that should be referred to in the Paper; for Sir John Coode would have liked the Grand Western Canal lift, constructed early in this century, to have been mentioned, whilst Professor Unwin appeared to object to a description of a visit to the Gileppe dam, because it had been completed, as stated in the Paper, about thirteen years ago. He had described the Grand Western Canal lift in a book[1] some years ago; but he had subsequently been informed that the lift was no longer in existence, and that a French engineer had searched for it in vain. He considered that a short reference to so important a work as the Gileppe dam was of interest, especially as pointing out how easily it could be visited. Mr. Giles, in preferring the caution of the French engineer in relying largely upon his flight of locks, to the boldness of the Belgian engineer in trusting solely to lifts, must bear in mind the difference between the two cases. At Fontinettes, the lift merely supplemented the existing flight of locks, on an old canal, where the traffic had become too large for the locks, and for the supply of water available. The Central Canal of Belgium, on the contrary, was a new work, along a portion of which, owing to a rapid ascent and a scarcity of water, flights of locks had been considered inadmissible, and, therefore, reliance had to be placed on lifts, or the scheme abandoned. Adopting Mr. Giles's simile, if gas had not been laid down, and could not be procured, it might be wise to rely upon electric light, rather than dispense with light altogether. Mr. Lloyd's request for further information about the lifts had been responded to by Mr. Clark; but he might add that the economy of the lifts must depend upon the traffic they accommodated, and the time and water they saved. Probably at Fontinettes, when the lift had got into thorough working order, the large traffic and the scarcity of water would give the lift a real commercial value. There was a good prospect of a large traffic along the new Central Canal of Belgium, on account of its forming a connecting link in a district of great industrial activity. The lifts, though costly, appeared the only means available for completing the waterway, and might, by a full utilization, afford a satisfactory return. The State also would have the advantage of reaping the indirect profits from any increase in trade resulting from, but beyond the limits of, the new canal, from which a company would derive no benefit. Mr. Barry had referred to unremunerative navigations and canals

[1] "Rivers and Canals," L. F. Vernon-Harcourt, p. 105.

in Ireland, and appeared to be opposed to the extension of inland navigation in England. No doubt it would be unwise to assume that every extension of inland navigation, or enlargement of existing waterways, must prove remunerative. Canals had suffered from inadequate size, absence of uniformity in depth, and in the dimensions of locks, want of energy in their development after the advent of railways, and diversion of attention and capital to railways. These defects had, however, been gradually removed in France; and traffic had been stimulated by exemption from tolls. Nevertheless, as he had pointed out in a Paper[1] read at the Canal Conference held by the Society of Arts in 1888, the traffic was quite small upon three-fourths of the length of the river navigation, and one-third of the canal system in France; and the very large traffic was confined to small sections in both. It was evident that, in spite of the improvement of the canals and river navigations in France, the greater portion of the system of waterways could not confer benefits on the community adequate to the cost of the works. Canal and river navigations might, indeed, be treated as roads, as, in fact, they were in France, being paid for and maintained by the State, and opened free of charge; but roads were absolutely essential for the whole population of a country, whereas waterways had a comparatively limited use; and it seemed hardly fair to tax the whole community for works which could be only advantageous to the few. If, however, waterways could not be considered as a universal public benefit or necessity, then evidently their improvement and extension must be restricted to those routes and districts where good prospects existed of a reasonable return on the outlay. He, therefore, quite agreed with Mr. Barry that caution must be exercised in proposing a great enlargement of English canals. He had, indeed, expressed a similar opinion in 1888, as shown by the following extract from the Paper referred to above: "The statistics, in fact, show that great caution must be exercised in the selection of canal routes for improvement, if they are to prove a commercial success, and that the scope for such schemes is strictly limited. Any attempt at a general revival and improvement of the canal system throughout England cannot prove financially successful, as local canals, through thinly-populated agricultural districts, could not compete with railways. Those routes alone should be selected for enlargement of waterway which lead direct from the sea to large and increasing towns, . . . or are suitably situated for the conveyance of coal, and general bulky Mr. Hare

[1] Journal of the Society of Arts, May 25th, 1888, vol. xxxvi. p. 753.

Mr. Vernon-Harcourt. goods, to populous districts."[1] At the same time, the large traffic and good returns on canals, such as the Aire and Calder Navigation, which were favourably situated, and had, by successive extensions, kept pace with the growing requirements of traffic, and the enormous accession of trade created by the canalization of the Main, showed that, under certain conditions, the improvement and extension of inland water communication might be very remunerative to the promoters, and effect a great increase in the trade of a district. It would, in fact, be as great a mistake to argue that because certain navigations in Ireland had not attracted an adequate traffic, therefore all improvements of inland waterways in England must prove unremunerative, as to suppose that every extension of inland navigation would benefit the promoters. Professor Unwin's criticisms of the portion of the Paper relating to the Gileppe dam had surprised him. The design of the Gileppe dam had certainly not been held up for admiration in the Paper, as it was expressly stated that its superabundant width imposed an unnecessary pressure on the base, comparing unfavourably in this respect with the Furens dam. This, being a fact, could hardly convey a wrong impression as suggested by Professor Unwin. He had also stated elsewhere, that "the maximum pressure on the Gileppe dam is considerably greater than on the Furens dam, in spite of its greater base and the smaller head of water, owing to the excess of material employed in its construction."[2] It was possible to praise the workmanship, and admire the height of the dam, without approving of its section. The section of the Vyrnwy dam was unquestionably superior to the Gileppe section; but it did not reach the economy of material attained in the Furens section, especially in its upper part.

Correspondence.

Duncan. Mr. J. DUNCAN observed that grain was conveyed from Rotterdam to Mannheim, a distance of 354 miles, by water, at rates varying from 6*s*. to 10*s*., and sugar was conveyed from Mannheim to Rotterdam for 3*s*. 6*d*. per ton. Where the traffic was large, $1\frac{1}{4}d$. per ton per mile would pay a good dividend on a carefully-constructed canal.

[1] Journal of the Society of Arts, May 25th, 1888, vol. xxxvi. p. 758.
[2] Encyclopædia Britannica," 9th edition, vol. xxiv. p. 407.

Professor H. Garbe, late of the German Embassy, stated that Pro needle weirs on the Poireé system, with iron frames and furnished Gar with the arrangement invented by Mr. Kummer, precisely similar to those on the Meuse and on the Main, were first introduced in Germany for the canalization of the River Brahe in 1877, some years before the commencement of the canalization of the River Main. The Brahe was a link in the water communication between the Vistula and the Oder, and was of great importance for timber traffic. The weirs on the Brahe stretched across the river; each weir was divided by a masonry pier, containing the fish-pass, into two bays, a deep and a shallow one. The deeper bay served for the discharge of the flood-waters, and had an opening of 15·90 metres (52 feet); its sill was 3·20 metres (10 feet 6 inches) below the water-level retained by the weir, or 0·70 metre (2 feet $3\frac{1}{2}$ inches) below the ordinary water-level of the river before its canalization; the iron frames with the Kummer arrangement were hinged at a distance of 1·20 metre (3 feet $11\frac{1}{4}$ inches) from each other. The shallower part had an opening of 10 metres (32 feet 10 inches), and served for the ordinary changes in the discharge of the river; its sill was 1·80 metre (5 feet 11 inches) below the water-level retained by the weir. The iron frames of this shallower part of the weir had been constructed on the Poireé system without the Kummer arrangement; the wooden needles having a length of only 2·50 metres (8 feet $2\frac{1}{2}$ inches). At the point where the Brahe joined the Vistula, the extensive port of Brahemuende had been established in the years 1877 and 1878 for the timber traffic. It had been divided by a dam, in which a large lock had been constructed, in order to pass the excess of water over the weir from the upper part of the port. The weirs on the River Brahe had given great facilities to the traffic. The details of this work for the canalization of the River Brahe had been published in the "Zeitschrift für Bauwesen,"[1] Berlin, 1888.

Sir Charles Hartley, K.C.M.G., observed that the information Si concerning the navigable condition of the Rhine and Main was He highly interesting; but having so recently visited the ground, the Author might perhaps be able to add some additional particulars relative to the actual useful depth of channel between Frankfort and the head of the maritime navigation at Rotterdam. According to statements which were obligingly furnished to Sir Charles Hartley in 1884 by German engineers of eminence, the ultimate depth aimed at on the Rhine with the water at ordinary

[1] Vol. xxxviii. p. 212.

Sir Charles Hartley. low-water mark at Cologne, a level which corresponded with that of 1·50 metre (4 feet 11 inches) on the Cologne gauge, was a minimum depth of 2 metres (6 feet 6½ inches) between Bingen and St. Goar; 2·50 metres (8 feet 2½ inches) between St. Goar and Cologne, and of 3 metres (9 feet 10 inches) between Cologne and Rotterdam; and the question now naturally arose, how far had this programme been carried out? In 1884, when the Cologne gauge marked a less depth than 2 metres, vessels of deep draught could no longer navigate without lightening; and in 1882, when at certain shoals between Mannheim and Emmerich the useful depth fell to less than 1 metre, the operation of lighterage took place during one hundred and nine days, independently of the complete interruption of the navigation for several weeks, during the continuance of the high floods of that year. It had been stated, by Mr. Imroth, that the depth of the Rhine had been improved along a shallow portion of the river between Mainz and Bingen, by training works between Eltville and Oestrich;[1] that these works were commenced in April, 1886, and completed in January, 1887; that the total cost, including the opening of the by-channel, was estimated at £600,000, and that the result had been the acquisition of a channel which was now navigable for "the largest Rhine craft." On reading the latter remark, which was slightly vague, he was inclined to ask, Was it to be taken for granted that there was now a minimum depth of 2½ metres (8 feet 2½ inches) between Mainz and Bingen, when the water stood at 1½ metre (4 feet 11 inches) on the Cologne gauge? The Author, in describing the canalization of the Main, stated that: "The sills of the locks have been placed 8 feet 2½ inches below the water-level retained by the weirs, although the minimum depth of the river is only 6 feet 7 inches, in order to allow of a further deepening of the bed of the river, in the event of the minimum navigable depth of the Rhine being increased to 8¼ feet, by the erection of a lock and weir between Bingen and St. Goar, where, occasionally in times of drought, the depth falls to 5 feet." By implication, therefore, it might be concluded that there had been no effective increase of depth, of late years, between Bingen and St. Goar; and, further, that should the lock and weir project be carried out, it must have been assumed, by the designers of the work, that the physical condition of this section of the Rhine rendered it unadvisable to attempt its correction by the ordinary method of training-walls and a simple open cutting, as at Eltville-Oestrich. The proposed

[1] Minutes of Proceedings Inst. C E, vol. xcii. p. 445.

departure from the system of correction hitherto adopted on the Rhine would be a remarkable phase in its hydrotechnical history, and as the canalization would apparently afford an additional depth of but 1 metre between Bingen and St. Goar, no better illustration could be given of the immense importance which the German Government attached to the attainment of a suitable channel for "large navigations" from the frontier of Holland to Mainz, Frankfort, and Mannheim. The provision of such a channel, however, could only be secured by the establishment of a minimum depth throughout of at least 8 feet, which would be equivalent to a depth of, say, 12 feet at ordinary water-level; and until the maintenance of this depth was assured, it could hardly be contended that the ports above named had already been brought within the limits of "large navigations;" if by that expression was implied the provision of a water-way for the constant use of vessels of large burden, without being compelled to lighten at any part of their voyage. Reverting to the subject of the canalization of the Main, it would be interesting to learn what was the condition of the river between its confluence with the Rhine and the lowest lock at Kostheim, and if in this non-canalized section of the Main training-works had been constructed, or dredging resorted to, in order to maintain the required depth of channel. In considering the subject of extended water-communication in England, in connection with what had been done in that respect on the Rhine and its tributaries, it should be remembered that the cost of river and canal works in Germany, as in France and many other countries, including the United States, was defrayed by the expenditure of public money, for which no charges were levied on shipping. It was hardly to be supposed that in Great Britain, where railways were not owned by the State, as was generally the case on the Continent, Parliament would ever adopt the principle of subsidizing Canal Companies, by either subscriptions to the cost or guaranteeing interest thereon; for it would be argued—and doubtless successfully argued—that if canals were assisted in this way, railways should be dealt with in the same manner. It might be doubted whether, if the canalization of the Main had been the work of an unsubsidized Company, it would have been able to pay a fair dividend to the shareholders, if tolls were high enough to cover the interest and amortization of the capital expended. In connection with this hypothesis, and bearing in mind that railways in Germany were managed with reasonable profit to the State, it might also be inquired, What had been the effect produced on the tariff of the parallel railway

Sir Ch Hartl

Sir Charles Hartley. between Mainz and Frankfort, owing to the recent canalization of the Main? For although it was stated by the Author that the tonnage carried by rail had increased considerably of late, notwithstanding the completion of the rival route, he omitted to mention whether or not the augmentation had been brought about without any reduction of dues, or if the cost of providing additional quay-accommodation at the railway termini had been met by special rates on shipping making use of the quays. Sir Charles Hartley was convinced that, so far as England was concerned, and altogether apart from the question of ship-canals for ocean steamers, no water-route could be made to compete profitably with railways for inland traffic, except by deepening existing channels, and constructing new ones of sufficient depth, and provided with ample lockage-space to accommodate vessels of large burthen; in other words, that it was only by the provision of deep-water canals that vessels could profitably be made to compete with railway-trucks for the conveyance of heavy goods. The successive phases which had taken place during the last quarter of a century in the dimensions of the St. Lawrence and the great lake canals of North America, and of the canalized Seine below Paris, plainly indicated that experience had taught the same lesson in countries where canals were constructed by the State; and two striking instances of the effect of this lesson might here be cited:—1. In 1886, the Dominion of Canada decided upon further deepening the Welland Canal, which had been opened in 1837 for small vessels; deepened to 10 feet in 1867; and to 12 feet in 1882, so as to allow the passage of the largest existing lake vessels without breaking bulk, and a contract was concluded in 1886 to deepen the canal to 14 feet. 2. In the canalized Seine, between Paris and tide-water, where fifty years ago the navigable depth was less than 4 feet, and where, after the original canalization, it was but 6½ feet, there was now a minimum depth of 10 feet, so that vessels of nearly that draught could reach Paris at all seasons at the present time.

Mr. Kidd. Mr. W. KIDD considered it a noteworthy feature of the Paper, taken as a whole, that it showed that remarkable activity prevailed on the Continent in the development of inland navigations, and this even where the country was already well served by railways, which were in direct competition with them. The establishment of two ports, such as Frankfort and Mannheim, on the imperfect natural waterways of the country, at a distance from the seaboard so great as 300 miles, and with a yearly traffic in the former of 400,000 tons, and in the latter of 1,796,000 tons

quantities together aggregating as much as the traffic of the Port of Hartlepool, was a most striking testimony to the value of inland waterways as highways of commerce. In the case of Frankfort, the traffic had been brought up from 10,000 to 400,000 tons by the deepening of the river from 3 feet to 6½ feet. This showed the immense value of the increased depth of water. Even with a depth of only 6½ feet, which limited the size of vessels to 1,000 tons, it was a large volume of traffic, and showed what might be done with deep-water canals. The Main was an instance of a river where the requisite increase of depth for navigation could best be obtained by canalization. The fall of the bed was only 19 inches per mile, and this suggested that an open trained channel might have been adopted; but the scour in the river was clearly too small to obtain a depth of 6½ feet by training-works, unassisted by such an amount of dredging as would have rendered the latter a more costly method than that adopted; and it was doubtful whether that depth could have been maintained when the river was low, especially if, as he understood was the case, the river was heavily charged with detritus. In cases, however, where the required increase of depth for navigation could be obtained by training and deepening, he should prefer that method, as one which offered no impediments, in the form of locks and weirs, either to the navigation or to the passage of the flood-waters. With the movable weirs, which had been adopted in the case of the Main, there appeared to be little objection on the latter score. He should like to ask what were the means of propulsion employed in the vessels, and whether any difficulty was experienced in navigating them up or down stream in flood-time; and whether there was any reason for the differences in the widths of openings in the various weirs, other than the original width of the river at the places named. Hydraulic canal lifts were an important adjunct to canal navigation, which appeared to possess the advantage over locks of saving a large volume of water, and, in high lifts especially, of much valuable time, while their first cost must, he thought, be much lower. A statement of the cost of those described in the Paper would be useful for comparison. He saw no reason why these lifts should not be applied to much heavier loads, and, where necessary, to even greater heights of lift; though he thought it would rarely happen that a greater lift than 55½ feet could be required at one place on a length of canal. The great saving in time, of passing vessels from one level to another in a high lift, must greatly increase the traffic capacity of a canal in a steep country, and he considered this

Mr. Ki

Mr. Kidd. the chief advantage of the lift, as much time was occupied in locking in an undulating country. He should like to be informed of the particulars of the sections of the quay-walls at Frankfort, which he observed had been executed at a cost of £6 per lineal foot. The subject of inland navigation was being actively revived in this country, as shown by the construction of the Manchester Ship Canal, and the promotion of numerous canal schemes for other towns. It seemed to him most important, in laying down a system of canals for a country, to fix upon some uniform section, particularly in regard to depth of water and width of locks; so that, in a completed system, vessels could pass over it in its entirety. In an island the canals might be divided into two classes: 1st, ship canals passing from sea to sea; of which the Manchester canal might ultimately form a portion, say, from the Mersey to the Humber; and 2nd, canals between inland towns. In the former, having regard to the ever-increasing size of ocean steamers, he thought there should not be less than 30 feet depth of water, and ample width. The question of uniformity of section in canals seemed likely to become quite as important as uniformity of the gauge of railways.

Lindley. Mr. W. H. LINDLEY observed that the training-works executed on the River Main, anterior to the canalization, were intended to give a normal depth of 3 feet at lowest water; but they had entirely failed to accomplish this result; boats drawing more than half this depth of water were unable to navigate the river during its lowest stages. In this case, therefore, training-works had proved ineffectual to attain anything like a depth adequate for purposes of navigation, although the basin of the River Main was nearly twice as large as those of the Thames, Trent, and Severn put together. Although the canalization works were only completed in 1886, and had only come into effective operation in 1887, traffic had so much increased, being now seventy-three fold what it was in the last years before the opening of the new works, that an inquiry had just been held by order of the Government, in the middle of February, and it had been decided: First, to increase the depth from 2·00 metres (6 feet 6½ inches) to 2·50 metres (8 feet 2½ inches). Secondly, to form a channel of this depth to facilitate the entrance from the River Rhine into the Main. Thirdly, to provide the locks with a third pair of gates, giving a length of 355 metres (1,165 feet), so that two trains of four of the largest boats each could be locked at one time; and to carry out various further improvements and extensions to meet the constantly increasing demands. This was the best proof that the works had

been a success. With reference to the sewerage of the city of Frankfort, the works had been designed in 1863, and carried out by his father, Mr. W. Lindley, from 1865 to 1878, at which date he undertook their further direction and extension, and especially the designing and execution of the purification works. Mr. Lindl

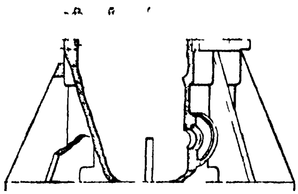
Mr. L. LUIGGI had had the opportunity of seeing most of the works described in the Paper, when returning from the Frankfort Congress, where he had acted as one of the delegates of the Italian Government; and was glad to express his concurrence with the Author's views as to the importance of all these enterprises. The hydraulic canal-lifts, and the works of canalization of the rivers referred to, deserved to be studied under all aspects by those interested in inland navigation. It was the more so, because this means of communication seemed to be recovering the importance which had been shortsightedly wrested from it by the prevalence of the mania for railways, the supporters of which maintained that inland navigation was a thing of the past, which had better be completely abandoned. All the works of canalization were admirable from the simplicity of the means adopted, and the large results which had been achieved. The Paper contained summary descriptions of some of the flourishing ports on the Rhine; but Mr. Luiggi would add a few particulars concerning the new port of Frankfort-on-Main. The latter was a model of what a fluvial port should be, and in certain respects also of what should constitute a seaport. Among its various details, the shed for goods in transit was worthy of especial mention. It was constructed of columns and girders of rolled iron, covered with a roofing of galvanized corrugated iron, the spaces between the columns being provided with coiling shutters of steel. By this means, it was capable of being converted, in case of need, into a warehouse, while, by rolling up the shutters it became again an open shed. Its cost had been 40 marks per square metre (£1 13*s.* 6*d.* per square yard), including foundations and revolving-shutters, and the cost of the latter was largely compensated for by the convenience afforded. Sheds of this type with coiling shutters existed in the harbour of Genoa, copied from those erected by Mr. A. Manning at the Tilbury Docks on the Thames, and gave entire satisfaction. Also, at Genoa, all the existing sheds, of the old type, were, at the request of the traders, being furnished with the coiling shutters, and the remaining ones to be erected at Genoa would be at once provided with this improvement. Another interesting feature at Frankfort was the provision of hydraulic traversers, for shifting the wagons on the railway lines along the quays and sidings. These Mr. Luigg

Luiggi. traversers were constructed on the principle of the American cable-tramways, and did not cause any incumbrance on the quay-roads. A wire-rope travelling in a small tunnel under the quay imparted a motion of translation to the traverser, and also to a small capstan on the latter. In this way the wagons were automatically brought under the traverser, shifted from one line of rails to another, or bodily lifted and transported to different positions. The wire-rope was actuated by a rotary hydraulic engine. In positions where there was little space, and where curves could not be introduced, these hydraulic traversers were most useful, and were preferable to turn-tables. The coal depôt at Frankfort was arranged in a convenient manner, worthy of imitation under similar conditions. For discharging coal from the vessel, stacking it, and loading in trucks, the principle of the grain-elevator was adopted, although the details were not the same. The coal was loaded into large buckets, which were raised by hydraulic cranes, and deposited upon small trolleys running on a network of elevated tramways, laid on the top of a timber scaffolding about 27 feet above the level of the quay. The trolleys were pushed by hand to the stack, and there emptied. In this way, little by little, the coal was raised to a height of 24 or 27 feet, at a distance of about 100 metres (328 feet) from the point of discharge. The railway trucks, in which the coal was to be carried to its destination, were stationed at convenient positions near the heap, so that the coal could be easily shovelled from the stack into the trucks. By this means, the discharging and stacking of coal was effected independently of its being loaded into trucks and run to the sidings. The two operations were conducted at two different levels. This system was, perhaps, capable of further improvement, especially in the direction of avoiding breakage of coal. Nevertheless, it was extremely simple and ingenious, and was worthy of being made known for further application, especially in the Mediterranean ports, where the coal arrived chiefly in ships from England, while at Frankfort it arrived chiefly from Westphalia by branches of the Rhine. Mention might also be made of the granary constructed of an iron framework filled in with hollow bricks, by this means dispensing with the necessity for deep and costly foundations. Electric light was used in this warehouse, one 16-candle power glow-lamp being provided for every 80 square metres (861 square feet) of floor-area. For all these reasons, a visit to the new port of Frankfort, especially if made under the guidance of Mr. W. H. Lindley, the Engineer of the city, could not fail to be highly interesting and instructive.

Mr. L. B. Wells noticed that the Author referred to the Anderton lift as the prototype of the larger ones at Fontinettes and Louvière, and to the alteration in design by which the saving of "weight by immersion" was effected; and this was characterised as "an important improvement." Theoretically this was so, and if the experience gained at Anderton had been sufficiently taken to heart, both by those responsible for the design and for the workmanship; that was, if all were perfect, there would be no need of a water-cushion, as at Anderton. Having had charge of the Anderton lift at the time of the accident, and for several years previously and afterwards, he thought the Institution would like to receive an account of this, especially as it happened at a critical time in the history of the larger lifts, and caused a material alteration in the design of the presses of both of them. From 1875 to 1882 the lift at Anderton worked without let or hindrance, when an accident of a very serious nature occurred, fortunately unattended with injury beyond damage to one of the presses. The up-river trough, or caisson, had been raised to the top, and the aqueduct gate lifted about 1 foot, preparatory to levelling up the water in the trough for passing a boat from the aqueduct, when a burst occurred, and the trough fell to the bottom. The water from the aqueduct rushed through the opening under the gate, into the descending trough, forcing the stern of the boat against the gate, and damaging the rudder, but beyond this, and some trifling damage to the upper works, there was no further injury to the boat or to the lift. It was impossible to determine at what speed the trough reached the bottom; but although the head of the press was burst, the escape of water was regulated by the space between the ram and the press, the diameter of the former being 3 feet, of the latter 3 feet 1 inch; to this, and to the fact that the trough dropped on to a water-cushion, its freedom from damage was due. A workman was in the tunnel greasing the ram at the time, and, hearing a run of water, looked round and saw a stream spurting from the connecting-pipe and press; he turned to go, when a burst took place; he was carried off his legs by the rush of water, but fortunately got to the bottom of the ladder, up which he scrambled. On pumping out the water from the tunnel, it was found that a side of the press had blown out (Figs. 3 and 4), and the pressure-pipe leading to it was cracked. In the investigation of the cause of accident, and the subsequent repair of the lift, Mr. Leader Williams and the late Mr. Duer were consulted. In the first instance, it was determined to test the second press, and it was arranged that the additional weight required

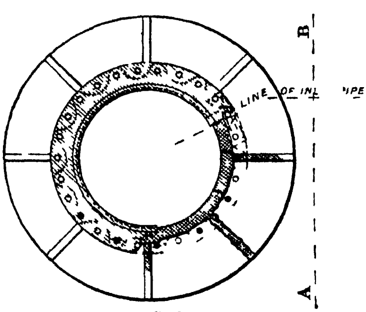
Mr. Wells. to bring up the pressure to 800 lbs. on the square inch should be placed as a dead-weight in the trough. This was done by stacking 120 tons of iron in it; making the total weight, when filled 5 feet, the ordinary working depth of water, 360 tons, or 50 per cent. above the weight of the descending load under the ordinary circumstances of working. The test was commenced at 12.37 P.M., with a sufficient depth of water to make up the ordinary weight of 240 tons, giving a pressure of 530 lbs. on the square inch; water was admitted at both ends of the trough by pipes. This went on steadily, the depth of water being increased about 18 inches, equal to 50 tons per hour, until 2.10 P.M., when the pressure was taken off and an examination made; at this time nothing appeared to have moved. At 2.35 P.M., the depth of water in the trough having reached 4 feet, giving a pressure of about 700 lbs. per square inch, the trough sank steadily, and on pumping out the water, it was found that the packing from a joint of the pressure-pipe had failed. This joint was re-made, and at 3.48 P.M. the pumps were again set to work, and the trough lifted up to the former mark, about 5 feet off its bearing. It was noticeable throughout the testing that there was a slight leakage; but whether this took place through the valves only, or through some of the joints as well as the valves, it was impossible to ascertain. At 4.32 P.M. the water had risen to 4 feet 7 inches in the trough; at 4.50 P.M., to 5 feet; and this being the full depth of water required, the supply was stopped, and the trough was held in position for about a minute. Orders had been given to start the engine to lift the trough about 5 inches up to the original mark, when it descended rapidly. On pumping out the water from the tunnel, it was found that the top ring of the second press had cracked through the hole for the inlet pipe, the crack being about $\frac{1}{4}$ inch wide. It thus appeared that the second press failed

FIG. 3.



ELEVATION AT A B

FIG. 4.



Scale $\frac{1}{48}$.

in the same place as the first; but the failure was of a very Mr.
different character. Firstly, the pressure under which it broke was half as much again in the latter instance. Secondly, instead of a large piece of the side of the press being blown out, a single crack was found. It had been suggested that the failure of the press was due to settlement, either owing to insufficiency of foundation, or to the abstraction of rock-salt from underneath the foundation, and consequent settlement of the overlying strata; but, as the two presses broke on the side next the central valve-box, this theory was untenable; it was also suggested that the leverage induced by the extended ram might have torn out the side of the press; but again, the second press broke when only raised 5 feet, so this idea was proved to be incorrect. Before proceeding to repair the press, it was determined to cast an experimental length of top press of cast-iron, 2$\frac{7}{8}$ inches thick, especial care being taken as to the quality of the metal and mode of casting, and that this should be tested to destruction under hydraulic pressure (Figs. 5, 6, and 7). The orifice was retained 5 inches in diameter; this casting broke under a strain of 2,856 lbs. on the square inch. The fracture was nearly perpendicular through the centre of the inlet, passing to bolt-holes on either flange. The result confirmed the opinion that the use of cast-iron might be continued, and that the orifice needed alteration. In comparing the strains upon the metal with other presses, no cause for failure appeared. In the presses of the Victoria Dock the working pressure was taken at 2 tons per square inch; these presses had been at work since 1857, during which time only one out of thirty-two presses had burst, and this was owing to a valve not being opened, so that an undue weight, which should have been distributed over many presses, was thrown upon this one. There had been no failure in the presses of the Malta or of the Bombay docks, which had been at work for longer periods than the Anderton lift, where the

FIG. 5.

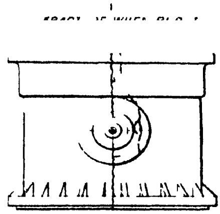


FIG. 6.

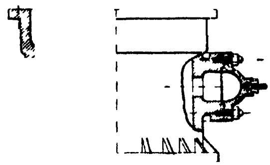
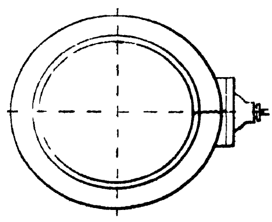


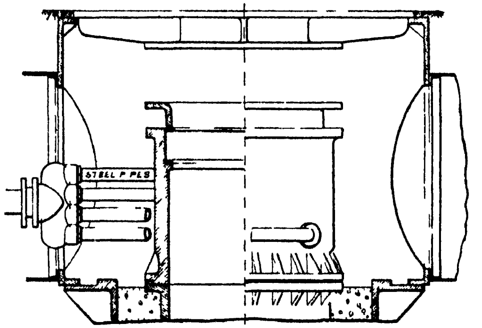
FIG. 7.



Scale $\frac{1}{24}$.

Mr. Wells. ordinary working pressure was 17 cwt. per square inch, and was said to be often exceeded at Malta. They were smaller in diameter, and the metal was thicker, and therefore not likely to be so sound, nor to be so uniformly strained, as the castings at Anderton. The Anderton presses were made of a mixture of iron similar to what was used in the Bombay presses. While deciding to continue the use of cast-iron for the press-heads, it was determined to alter the form of the casting, and to diminish the size of the orifice; for it was evident that the abstraction of the metal to the extent of 5 inches was a mistake, and that the method adopted to endeavour to compensate for this loss, namely, by thickening the metal round the orifice, was likely to produce a bad casting where it was most important that the metal should be soundest. The diameter of the orifice was fixed at 2 inches; the

FIG 8



Scale $\frac{1}{24}$.

number of orifices was increased to four, and the 5-inch pipe was led into a steel distributing-box, from which four steel pipes, 2 inches in diameter, ½ inch thick, were connected with holes drilled at various levels, and in different positions on the side of the press-head. The metal of the press was cast 3¾ inches thick, and the large bottom flange- and side-stiffeners of the original press-head were abandoned (Fig. 8). The new presses had proved satisfactory. In 1884 it was found that the rams between the top of the tunnel and the surface of the river-water, for a length of 8 feet, were becoming grooved or corded, to such an extent as to allow of the passage of an undue quantity of water, while this length was moving through the gland. The rams were repaired by letting in bar-copper wherever necessary, a similar method having been tried at the Victoria Lifting Dock, and found to give better results

than any other expedient. About this time the experiment of Mr. W‹
casing the portion of a ram working in the water of the dock with a covering of drawn copper was tried, and answered so well that the Dock Company now had upwards of a dozen similarly cased. Much inconvenience having been experienced by similar cording of rams in the numerous packing-presses in Manchester, two methods had been adopted to avoid the difficulty:—1. To turn down the ram and pass over it a casing of copper or brass, $\frac{3}{4}$ inch in thickness; 2. To electrically deposit copper on the surface of the ram, the union of the two metals being so thorough that the copper wore away before becoming detached. Both these methods had been in use for several years, and had proved successful, the damage to the leathers, which previously were constantly needing renewal, having been reduced to a minimum. Cast-steel was in many places being adopted for packing-presses in lieu of cast-iron. The presses had a lift of about 6 feet, and worked up to 50 to 60 cwt. per square inch. Some twenty years ago the rams were 9 to 10 inches in diameter; when the diameter was increased to 14 inches, cast-iron presses $7\frac{1}{2}$ inches thick were provided; as many of these failed, Low Moor metal was tried, 5 inches in thickness, but many of these failed also. Of late years, rams 18 inches in diameter had come into use, with cast-steel presses 3 inches, and even less, in thickness, giving good results. Cast-iron presses had been strengthened with wrought-iron hoops in Manchester; and presses up to 30 inches diameter, made of Whitworth metal, were also working under high pressure. The information given by the Author, on the traffic resulting from the improvement of the navigation up to Frankfort, should convince the public of the great advantage of water-ways, and should lessen the hostility of Railway Companies to their improvement in this country. It proved that where there was trade to be accommodated, there was traffic suited for each description of locomotion; that barges would push inland as far as there was water to float them; and that large cargoes induced cheap freights, while the railways benefited by the general increase of business in the district. As Mr. D. Adamson had pithily put it, "What would there be left for the railways to do on Tyneside, if the river were not navigable?"

Mr. Ve Harcou
Mr. L. F. VERNON-HARCOURT, in response to Sir Charles Hartley's inquiries, might add that no works had been carried out very recently between Bingen and St. Goar, with the object of securing the desired minimum depth of 6 feet $6\frac{1}{2}$ inches along this part of the Rhine, which was the shallowest portion below Mannheim. At the present time, the minimum depth of water at the low-water

Vernon-Harcourt. level of 4 feet 11 inches on the Cologne gauge, was 6 feet 6½ inches from Mannheim, and from Frankfort to Bingen; 4 feet 11 inches between Bingen and St. Goar, increasing to 7 feet 2½ inches about half way between Bingen and Coblenz, and maintaining this available depth down to Cologne; and 7 feet 10½ inches from Cologne to the German frontier below Emmerich. The shallow portion below Mainz, between Eltville and Oestrich, had been deepened by training works to the navigable depth of the portions above and immediately below it. The physical conditions, however, of the river were quite different between Bingen and St. Goar, to what they were between Eltville and Oestrich; for the river passed below Bingen through a narrow rocky gorge, and had a considerably greater fall than elsewhere, instead of through the flat plains and with the very moderate fall which extended from Mainz to Bingen. The improvement works, therefore, proposed for obtaining a better navigable depth between Bingen and St. Goar, naturally differed from those which had been successfully carried out between Eltville and Oestrich. No decision, however, had as yet been arrived at; and he understood that some objections had been raised against placing a lock in the open Rhine navigation. With reference to the condition of the River Main between Kostheim and the Rhine, the depth of water was apparently sufficient except near Kostheim weir; and this shallow portion was avoided by the ordinary navigation by extending the deep embanked lock channel down to the deeper part of the river; but the proposed increase in minimum depth to 8 feet 2½ inches, referred to by Mr. Lindley, would necessitate a lowering of the bed along this portion. In reply to Mr. W. Kidd's questions, he was not aware of any reason for the different widths of the weirs on the Main, beyond the corresponding differences in the width of the river. The cost of the Louvière lift had been given by Mr. L. Clark as £50,000; but besides the additional cost due to its being Government work, there were the approach aqueducts, both there and at Fontinettes, which would not be essential adjuncts to all lifts, and which raised the price in these instances. Uniformity in the depth of water and in the dimensions of locks was quite as essential for canals as uniformity of gauge for railways, as he had pointed out in his Paper[1] at the Canal Conference of 1888; but, unfortunately, the network of English canals was very defective in this respect, and no general scheme had been adopted, as in France, for securing uniformity all along the main routes of the canal system. In

[1] Journal of the Society of Arts, May 25th, 1888, vol. xxxvi. pp. 754–757.

France, however, a general alteration of the main canals, where **Mr. Vern Harcourt** necessary, to provide a uniform waterway, was a mere question of cost, as the canals were almost exclusively under Government control; whereas in England, the divided ownership would necessitate extensive combinations, facilitated by Government, before any general plan for providing uniform waterways along the main routes could be undertaken. Steam tugs conveyed trains of barges along the Rhine and Main; the system of towage on a sunk cable was used on the Rhine, only on the section between Obercassel, a little above Bonn, and Bingen, and it was introduced on the Main between Mainz and Aschaffenburg, above Frankfort, in 1886; but this system had been abandoned on the Meuse and the Danube. He was glad that his description of the lifts had elicited some interesting particulars from Mr. Wells, about the failure of the press at the Anderton lift; and there was no doubt that this failure afforded valuable experience for designing the presses at Fontinettes and Louvière. Useful additional details about appliances for trade at the port of Frankfort had been supplied by Mr. L. Luiggi; and Mr. W. H. Lindley had given a remarkable confirmation of the success of the works on the Main, by his reference to the further improvements decided upon within two years of the completion of the works.

"Economy Trials of a Non-Condensing Steam-Engine: Simple, Compound and Triple.

By Peter William Willans, M. Inst. C.E.

Reply of the Author to the Correspondence.[1]

Willans. Mr. P. W. Willans, in reply to the correspondence, observed with reference to the objection raised by Mr. G. R. Bodmer to the term "missing feed-water," when used in the sense of the difference between the weight of steam shown by the indicator to be present at any point other than the point of cut-off, and the weight of water pumped into the boiler, that he admitted that the meaning of the expression might have been more clearly explained, but he was not ignorant of the fact of condensation due to work, or of its bearing on the amount of water present at later stages in the expansion. He had not thought it desirable, however, to attempt to sub-divide the missing quantity in the manner indicated by Mr. Bodmer for reasons which he would give presently.

Another somewhat elementary difficulty had been experienced by Professor R. H. Smith, who could not reconcile the formula, "given on the authority of Mr. J. MacFarlane Gray, with the ordinarily accepted equation for the same thing, except for small ranges of temperature; but the values of $\frac{A - B}{A}$ occurring in steam-engines ran up to $\frac{1}{4}$." Mr. Gray did not intend the formula—

$$\left[U = \left(\frac{1{,}438 - 0 \cdot 7A}{A} + \frac{A - B}{A + B}\right)(A - B)\right]$$

to be in any sense an approximation to $\frac{A - B}{A}$. The latter expressed the efficiency of heat in an elementary engine working between the temperatures A and B, and the former, the work due from 1 lb. of steam at temperature A, expanded in an adiabatic cylinder from the temperature A to the temperature B, and exhausted at the latter temperature. Professor Ewing had said: "The Author appeared to expect more initial condensation when the boiler-pressure was high than when it was low. On the contrary, he should expect, *cæteris paribus*, that with dense steam,

[1] Minutes of Proceedings Inst. C.E., vol. xciii. p. 243.

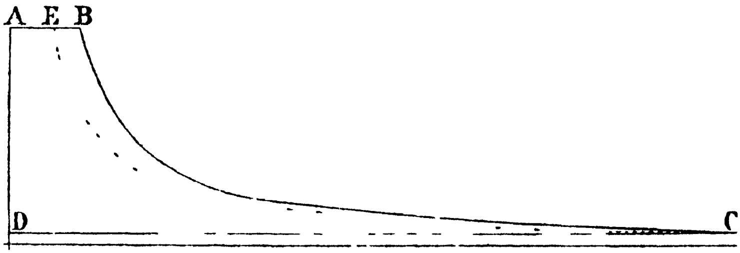
the portion condensed would be a smaller fraction of the whole." Mr. Willans was not, however, speaking of the percentage condensed as given in line 31 (Table VII), but of the absolute quantity condensed per unit of time, in line 28 of the same Table, which showed practical equality at all pressures. It might have been more correct to refer to the heat transferred, as given in line 34; for the heat abstracted to effect condensation of steam at its own temperature was less at the higher than at the lower pressures. Professor Ewing further said that "when the Author spoke of the most perfect engine possible working under ideal conditions, he was not speaking of a thermodynamically reversible engine following Carnot's cycle." The "most perfect machine possible" was Clausius' description of the engine which he had taken as his standard—and he thought he correctly described it. It was an engine which made absolutely perfect use of the energy supplied to it, taking into consideration the conditions under which it was supplied. In the Carnot cycle, the heat was all received at the higher temperature, while in the steam-engine this was not so. He was not concerned to discuss the thermodynamic reversibility of his standard, and evidently there was a misconception as to the meaning of the term "reversible," for, speaking of the same cycle Professor Ewing observed: "The cycle in such an engine was not reversible, on account of the absence of adiabatic compression;" whereas Dr. John Hopkinson had previously said: "The cycle of operations was a perfectly reversible cycle." Apparently great divergence of opinion prevailed as to the standard of comparison which should be adopted. Mr. W. W. Beaumont and Mr. C. E. Cowper pointed out, during the discussion, that in many cases the comparison of water used with water theoretically required was misleading, the efficiency as given being higher in certain cases in which the feed-water was greater, and Mr. Mair and Mr. Cowper thought the efficiency should be based on a comparison of the heat supplied with the heat given up in useful work. He agreed with Mr. Cowper that this was the only way of taking the "absolute efficiency," but he might observe that this method of comparing the efficiency was quite as misleading as a comparison of the feed-water; because it took no account of the limitations which the working conditions themselves imposed, whereby the temperatures at which heat was received and was rejected were unalterably fixed. The object of such a comparison was entirely different to that which he wanted to make. The comparison of heat received with heat utilized, or absolute efficiency, was, he thought, mainly useful in contrasting

Mr. Will

Willans. different types of heat-engine from the physicist's standpoint, say a gas-engine and a steam-engine, or in determining the theoretical advantage of using steam of very different temperatures as in steam-engines; but when, as in this case, the object was to ascertain how closely a given steam-engine approached the perfection theoretically possible, such a comparison was useless. With an increased range of temperature, an increased absolute efficiency was to be expected, and no credit was due to the engineers for that, and the mere comparison of heat supplied with heat utilized did not allow for the increased efficiency due naturally to the greater range of temperature. It had been pointed out that only about 15 per cent. of the heat supplied was utilized in even the best engines, and Professor J. Perry said:—"Surely there was no fact which ought more constantly to force itself on the attention of engineers, than that they were spendthrifts who were wasting their fortune in coal laid by for them during millions of years." But, in reply to such arguments as this, he would say that it was of still greater importance to realize the fact, that there were hard and fast barriers which could not be passed, seeing that it was physically impossible to get back more than a fraction of the energy supplied to any heat-engine. It was therefore absurd to use a standard of comparison which the working conditions themselves rendered it impossible to approach. The losses which could be avoided theoretically, and which alone it was desired to measure, were thereby rendered insignificant, and became merged in the larger losses due to nature. The practical use of any standard of comparison to an engineer, was to enable him to ascertain what still remained to be done by him in improving the apparatus employed. He denied that, in adopting the standard of Clausius, he had fallen foul of any thermodynamic laws; on the contrary, he had most strictly adhered to them. The diagram taken as the standard of perfection might be described as one due from 1 lb. of steam admitted to a cylinder at the higher temperature, expanded adiabatically to the lower temperature, and expelled at the lower temperature. Professor Smith had pointed out that in vol. xciii. Fig. 1, Plate 3, the lower curve, giving feed-water theoretically required, was found from the equation which involved B, the exhaust temperature, but that it was not stated which B had been used in working out the results. The engine being a non-condensing one, the B used was that answering to the atmospheric back-pressure 212° Fahrenheit, or 673° Fahrenheit absolute. The area of the diagram named above was a measure of the work possible between the given limits of temperature, and a

comparison between the work represented by it and the work Mr. Wills
obtained from each lb. of steam in the engine was, he contended, the most accurate comparison possible, and by far the most useful one. The difference between the two in no way depended on the natural limitations in any particular case, but was a measure of those practical imperfections only which it was the object of engineers to reduce to a minimum. Fig. 24 showed such a diagram, A, B, C, D. Its area in heat-units was the U of Mr. Gray's formula, and the W_1 of Clausius. The formula given by Dr. Hopkinson was identical with the latter if the specific heat of water was taken as unity, and if the steam was assumed to be dry. Considerable deductions had to be made from the area of this diagram in practice. Owing to initial condensation, the expansion curve usually followed more nearly the direction of the dotted line E C,

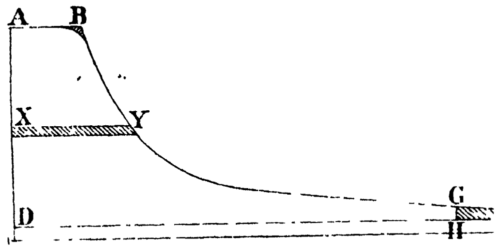
FIG. 24.



the proportion of the 1 lb. represented by $\frac{E\,B}{A\,B}$ being the steam condensed on entering the cylinder. If initial condensation could be entirely prevented, by subdividing the stages of expansion, and running at high rotative speeds, the losses which remained would be mainly those due to back-pressure caused by friction of the steam in the passages between one cylinder and another, and those due to incomplete expansion.

In Fig. 25 the former were denoted by bands such as X Y, and the latter by the loss of corners such as G H C. This particular corner was always a necessary loss, because in no case could it be worth while to carry the expansion beyond the point at which the pressure G H equalled that necessary to drive the engine itself. He had, however, not deducted this corner in the area of the diagram used in the Paper, but had used the whole area, A B C D, as the standard of comparison. It was for the purpose of measuring

Willans. these and other practical losses that the standard of efficiency adopted in the Paper had been chosen. This standard clearly enabled these losses to be measured more accurately than could any of the other plans. He should like, however, to discuss the matter also from a thermodynamic point of view, as it had been asserted that his standard was an unusual one. Professor J. H. Cotterill had said:—"In estimating thermodynamic efficiency, the Author considered as perfect, not an ideally perfect heat-engine for the limits of the temperature employed, but an engine working under conditions more nearly approaching what was possible in practice. Much might be said in favour of this method; but if it was adopted it should be remembered that the standard of perfection was an arbitrary one employed mainly for the sake of simplicity. It seemed, therefore, hardly worth while to employ the adiabatic curve as the standard expansion curve in place of the



hyperbola, which was not only more simple, but also more nearly represented the actual expansion curve under the most favourable conditions of working." This seemed to him a very curious argument. An inquiry was to be made into the extent to which initial condensation affected economy. The effect of such condensation was to modify the diagram until the expansion-curve approached more or less closely to a common hyperbola; and he contended that, on that account, it was the more imperative to use the true expansion-curve, and not the common hyperbola, as a standard. Whether the efficiency of what Professor Cotterill called an "ideally perfect engine," or of what Rankine called an "elementary engine," should be taken as the standard was another matter. It ought, however, to be borne in mind that what Clausius and Rankine meant by an elementary engine was "an element of the heat-work of an engine" only.

It had been argued that the proper standard of comparison

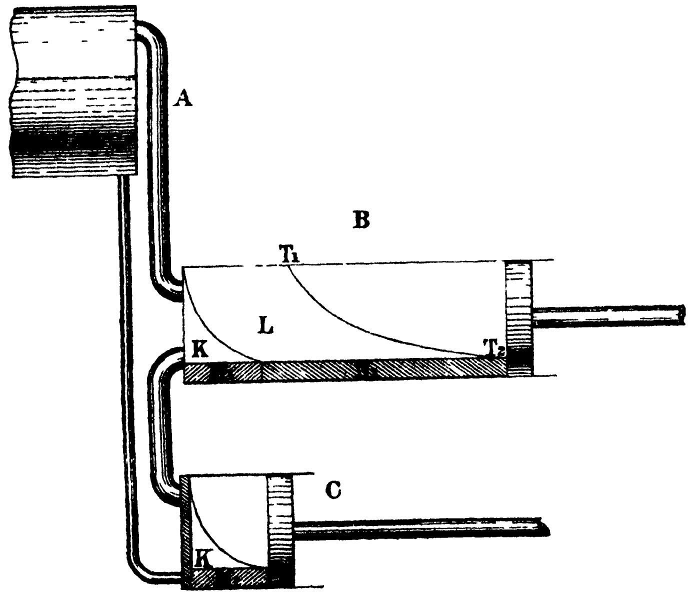
was the efficiency of the "elementary engine," which was that of the ideal Carnot cycle, and was represented by the formula $\frac{T_1 - T_2}{T_1}$, and that with this efficiency the absolute efficiency of any particular engine, or $\frac{\text{Heat utilized}}{\text{Heat supplied}}$, should be compared. But this could not be a fair comparison unless the heat supplied to the actual engine from without was all supplied at the higher temperature, and he maintained that the term "perfect engine," in the sense of the "ideal engine" receiving all its heat at the higher temperature, was misleading. If heat was only supplied at the higher temperature, a better return was possible than if it was supplied at various lower temperatures as well; and the perfection of any given engine could not be affected by the way in which the heat was supplied, but only by the use which was made of it. An ordinary steam-engine, to conform with fact, must be assumed to receive its heat at all temperatures between that of the exhaust-steam and that of the boiler-steam; and he did not see any more reason for comparing his steam-engine with one receiving all its heat at the higher temperature, than he did for comparing an engine using steam at 60 lbs. pressure with one using steam at 200 lbs. pressure per square inch. The difference between the two cases was merely one of degree. It was better to supply all the heat at the higher temperature than at various temperatures; so, also, it was better to supply it in the form of steam at 200 lbs. pressure, than as steam of 60 lbs. pressure. Mr. Willans.

The formula of Clausius (vol. xciii. p. 132) was based strictly on the assumption, that for each heat-unit supplied, the fraction utilized in work was represented by $\frac{T_1 - T_2}{T_1}$, T_1 being the temperature of supply for each heat-unit, and Mr. Willans, throughout the comparison, adhered most strictly to that formula, while some of his critics did not do so.

Professor Kennedy had given (vol. xciii. p. 227) three representative methods of arriving at the efficiency of an engine, and he proposed to consider these three methods fully. Speaking of the trial marked A in Table III he said :—"If the results of that trial were compared with the working of what was called a perfect engine, using the same weight of steam per stroke, and working between the same temperatures, the engine would have an efficiency of 84·2 per cent. of its highest possible efficiency. Such an engine would give, per lb. of steam received, an amount of work expressed

Mr. Willans. by $L_1\left(\frac{T_1 - T_2}{T_1}\right)$. To this comparison Mr. Willans objected, first, that in the cycle of Carnot, to which alone the above formula was ever intended to be applied by Rankine, Clausius, Tait, Thomson, Cotterill, Joule or Maxwell, heat, not steam, was used, the working fluid forming as integral and permanent a part of the engine as the piston or the connecting-rod. Heat alone was supplied to it, and part of that heat was converted into work.

Fig. 26.



It was an ideal conception, which could not be realized in practice, for it assumed a cylinder which would be non-conducting during expansion and compression, and yet capable of transmitting heat during the remainder of the cycle. To carry it out in practice, the operation of the cycle must be divided into three separate parts, as shown by Fig. 26, namely:—(1) A boiler, A, where the heat was supplied to the water to convert it into steam; (2) A cylinder, B, where the steam was used; and (3) A dynamic feed-heater, C, where part of the heat of the exhaust-steam was restored to the feed-water, by reserving and compressing a portion of the exhaust-steam in the presence of the feed-water, and

so raising the latter to the temperature of the boiler-steam before it was forced into the boiler. In such a system steam would be "used," and the heat supplied from without to the water in the boiler would all be supplied at the higher temperature; but part of the work done in the cylinder was devoted to driving the feed-heater. The total work done in the cylinder B during the forward-stroke was represented in foot-lbs. (Fig. 26) by the areas $K + L + M_1 + N_1$. The negative work during the back-stroke was represented by the areas $M_1 + N_1$; the energy of pv of the steam exhausted, by N_1; the energy of pv of the steam transferred to the feed-heater C, by M_1. The net work done in the cylinder, by $K + L$. The work done during the forward-stroke in the feed-heater C (*i.e.* during the transfer) was represented by M_1; the negative work during the back- or compressing-stroke, by $K + M_1$, leaving K as the negative work in the feed-heater to be deducted from the area $K + L$ in the cylinder, thus leaving L as the net positive work of the cycle. Mr. Will.

Professor Kennedy in his first comparison, therefore, treated the ideal engine unfairly, as he himself said; for the formula $L_1 \frac{T_1 - T_2}{T_1}$ was only the measure of the work done in the cylinder after deducting the work applied in actuating the feed-heater, while when dealing with the actual engine he credited it with all the work done in the cylinder; in fact, the comparison was that of all the work with only a portion of the duty.

The diagram from the cylinder B, or engine proper, represented by the areas $K + L$, without any deduction for the work absorbed by the feed-heater, was the standard of perfection used in the Paper, and in this he was in the strictest agreement with the formulas of Clausius and of Rankine. Taking Professor Kennedy's second standard:—"If, again, the engine was compared with a perfect engine receiving the same amount of heat as the Author's, supposing all the heat to be received at the temperature of the steam, the efficiency would go down at once to 71·4 per cent. The formula for the work theoretically possible for an engine of this kind, per lb. of steam, was

where h_1 was the heat necessary to raise 1 lb. of water . . . . from T_2 to T_1."

It was physically impossible for 1 lb. of water at T_1 to receive the heat $L_1 + h_1$ during the process of evaporation, and conse-

Mr. Willans. quently impossible for 1 lb. of steam to do work in such an engine $= (L_1 + h_1)\left(\frac{T_1 - T_2}{T_1}\right)$. That amount of heat would suffice for the evaporation of more than 1 lb. of water, as much more, in fact, as the fraction $\frac{h_1}{L_1}$ lb. in any particular case, and thus the work due (according to him) from an elementary engine, and represented by the formula $(L_1 + h_1)\left(\frac{T_1 - T_2}{T_1}\right)$ was not the work due from 1 lb. of steam, but from $\left(1 + \frac{h_1}{L_1}\right)$ lbs.

The comparison was between the work actually obtained from $(L_1 + h_1)$ heat-units employed in the actual engine to heat 1 lb. of water from T_2 to T_1, and afterwards to convert that lb. of water into steam at T_1; and the work due from $(L_1 + h_1)$ heat-units employed in the ideal cycle to convert $\left(1 + \frac{h_1}{L_1}\right)$ lbs. of water at T_1 into steam at T_1; and it was obvious that such a comparison was most unfair and misleading. It would indeed be just as reasonable to compare the work obtained from 1 lb. of steam, in engines using steam of 100 lbs. and 50 lbs. pressure respectively, working against the same back-pressure, and to find fault with the mechanism of the low-pressure engine, because the work obtained from it was less than that obtained from the high-pressure one. Professor Kennedy objected that he had taken a non-perfect engine as his standard. The limiting maximum of work, which it was theoretically possible to obtain from any given quantity of heat in an engine was known, as soon as the temperatures at which the heat was received and the waste heat rejected were defined; and to expect the duty of heat supplied at T_1 from heat supplied at any lower temperature, was to expect not merely perfection but a miracle. He had adopted the standard of Clausius, and compared the performance of his engine with that of an engine which made a perfect use of the same opportunities.

He would now take Professor Kennedy's third standard.

"The engine might be compared with a perfect engine using what Zeuner called the same 'heat-weight' as the actual engine, and working between the same limits of temperature. The amount of work done by such an engine, per lb. of steam, would be

$$\left(\frac{L_1}{T_1} + \log_e \frac{T_1}{T_2}\right)(T_1 - T_2),$$

"and compared with this standard, the efficiency in the particular

trial under discussion would be 69 per cent., or nearly the same figure as in the last case." Mr. Wi

To this he must object that in the case of 1 lb. of steam used in the actual engine and the Carnot cycle respectively, the heat-weights, or $\frac{\text{Heat units supplied}}{\text{absolute temperatures at which they were supplied}}$, could not be the same, so that he did not see how such a comparison could be made. In the Carnot cycle, the quantity of heat supplied to each lb. of steam $= L_1$ and the heat-weight $= \frac{L_1}{T_1}$, T_1 being the temperature at which the heat was supplied. In the actual engine the heat supplied was $L_1 + \Sigma \Delta Q$; or the latent heat at T_1 + the heat supplied to raise the feed from T_2 to T_1, and the sum of the heat-weights was $\frac{L_1}{T_1} + \log_e \frac{T_1}{T_2}$, the last term in this expression being $\int_{T_2}^{T_1} \frac{dQ}{T}$. Thus the heat-weights must be different in the two cases. The heat-weight of 1 lb. of steam in an elementary engine could only be the same as the heat-weight in an actual engine receiving steam at a higher temperature.

It was theoretically impossible for any conceivable engine, working between temperatures T_1 and T_2, to do work per lb. of steam $= \left(\frac{L_1}{T_1} + \log_e \frac{T_1}{T_2}\right)(T_1 - T_2)$ as stated by Professor Kennedy.

A practically correct expression, although not mathematically correct, would be—

$$\left(\frac{L_1}{T_1} + \tfrac{1}{2} \log_e \frac{T_1}{T_2}\right)(T_1 - T_2).$$

It was hard to have to compare the return from an actual engine, receiving heat at various temperatures, with the return from the ideal Carnot cycle receiving all its heat at the highest of these various temperatures; but it was far more so to have to compare it with a standard as in this case still higher. In using the standard of Clausius and Rankine, he considered that he had adopted one which threw a greater light on the behaviour of the engine than any of the others suggested in the discussion, and one which showed more clearly than any other could, the amount by which it fell short of the perfection theoretically possible. He could not agree with Professor Kennedy that the precise standard was immaterial so long as it was defined, and he maintained that there was one standard, and one only, by which the imperfections of any ordinary steam-engine could be accurately measured; that standard being perfection.

Willans. It was unfortunate that Mr. Gray's $\theta\ \phi$ diagram, to which he had referred in the Paper, was not more frequently used, as all these points could be shown much more clearly and quickly by it than by calculation.

He had been asked, since the reading of the Paper, to explain the agreement between the diagram and the formulas of Clausius and others, and he thought that it might be useful to do so here:—

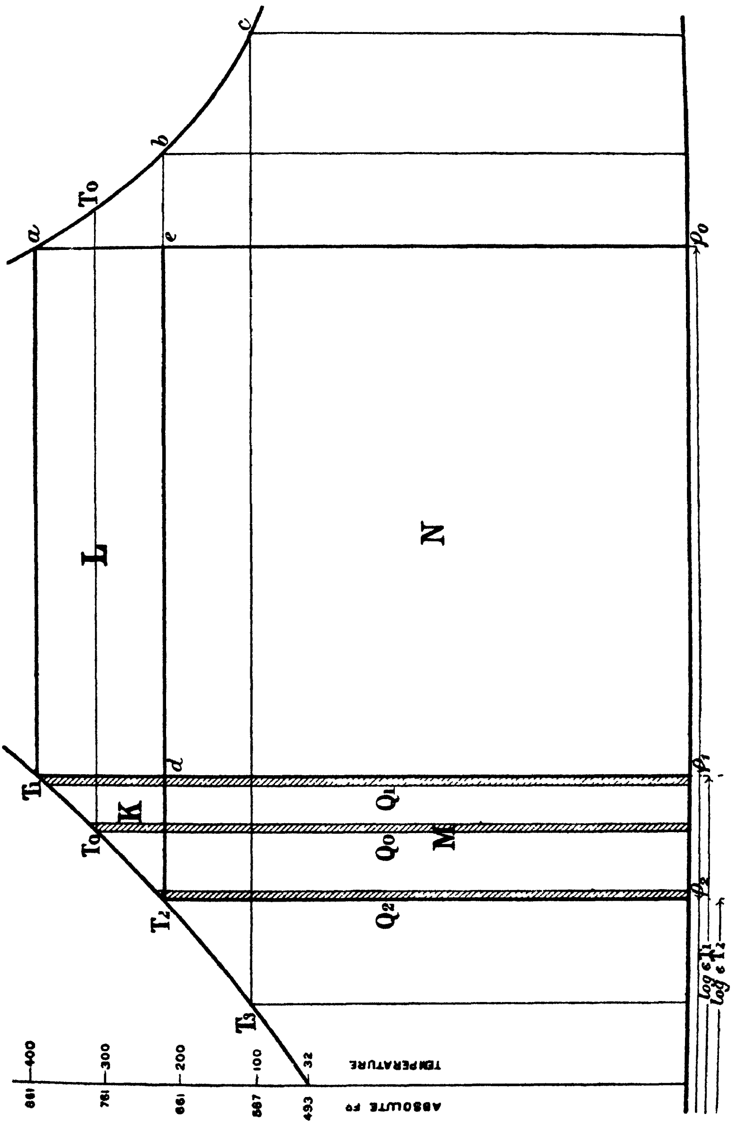
The diagram (Fig. 27), was a graphical representation of some of the most important thermodynamic laws, and related to 1 lb. of steam or water.

The base-line represented the absolute zero of temperature, and the vertical ordinates, such as $T_1\ T_0\ T_2$, represented temperatures in degrees absolute measured from this base-line; the area represented energy in heat-units. The curve $T_1\ T_2\ T_3$, bounding the diagram on the left, was of such a character that the area enclosed between any two vertical ordinates, as T_1 and T_2, drawn from it to the base-line, represented the number of heat-units required to raise 1 lb. of water from T_2 to T_1; in other words, the area in heat-units was equal to the difference of temperature in degrees. This was on the assumption that the specific heat of water was unity. The left-hand curve, $T_1\ T_2\ T_3$, was constructed by making the horizontal distance between any two ordinates T_1 and $T_2 = \log_e T_1 - \log_e T_2$. The curve bounding the diagram on the right was constructed by laying off to the right of each vertical ordinate $T_1\ T_2\ T_3$, and to the same scale for heat-units as above, a parallelogram equal in area in each case to the latent heat at that temperature, the curve passing through the right-hand corners *a b c* of these parallelograms. It was convenient to set out the diagram on sectional paper, and so to arrange the scale that the area representing a heat-unit was an aliquot part of a square inch.

Take, for example, 1 lb. of water at temperature T_2. From the construction of the diagram the heat-units necessary to raise it from T_2 to T_1 were represented by the areas $K + M$ enclosed between the vertical ordinates T_2 and T_1; and the heat necessary to convert the 1 lb. of water at T_1 into steam at T_1 was represented by the areas $L + N$. The area to the left of the ordinate T_2, and bounded by the curve $T_1\ T_2\ T_3$ and the base-line produced indefinitely to the left, represented the heat already in the 1 lb. of water at T_2. Heat added might be represented by a series of vertical bands, such as $Q_2\ Q_0\ Q_1$, and each sufficiently narrow for it to be assumed, without sensible error, that the heat was all received at one temperature.

When 1 lb. of steam was expanded in a cylinder from tempera- **Mr. Wil**

Fig. 27.



ture T_1 to temperature T_2, and then exhausted against the back-

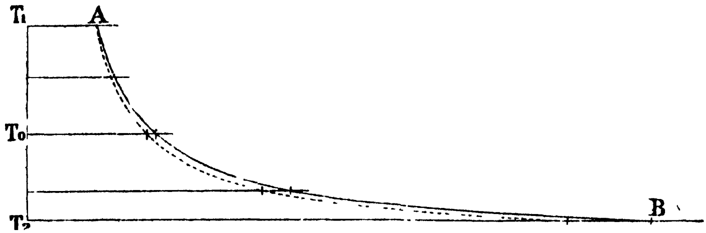
Mr. Willans. pressure corresponding to T_2, the work due from it was represented on the diagram by the areas $K + L$, or $T_2\ T_1\ a\ e\ T_2$.

At any period of the expansion, as, for instance, when the temperature had fallen to T_0, the vertical line $a\ \phi_0$ divided the horizontal line $T_0\ T_0$, in the proportion in which the original lb. of steam was, at the temperature T_0, divided into steam and water.

The adiabatic curve could be constructed for any particular case in a few minutes, whereas by other methods the construction was rather difficult, involving considerable mathematical knowledge, or a most complicated graphical process.

In setting out the adiabatic curve from this diagram, all that was necessary was to draw the saturation curve for steam as A B, Fig. 28,

Fig. 28



the line T_1 A representing the volume of 1 lb. of saturated steam at T_1, and T_2 B that of 1 lb. of saturated steam at T_2. At stages such as T_0, set off horizontal lines, and divide them in the same ratio as lines such as $T_0\ T_0$ were divided into steam and water on the $\theta\ \phi$ diagram at corresponding temperatures.

Returning to Fig. 27, the heat passing away with that fraction of the lb. of steam which was, during the return stroke, exhausted as steam, was represented by the areas $M + N$.

It would be seen that the areas $K + L$, representing the work due from 1 lb. of steam expanded from T_1 to T_2, and exhausted against a back-pressure corresponding to T_2, exactly agreed with Dr. Hopkinson's formula (Vol. xciii. p. 191), which, if the steam was assumed to be dry, and the specific heat of water was taken as unity, was itself identical with that of Clausius, given at the commencement of the Paper.

In Dr. Hopkinson's formula the work due from 1 lb. of steam, expanding between the temperatures T_1 and T_2, was represented by

$$L_1\left(\frac{T_1 - T_2}{T_1}\right) + (T_1 - T_2) - T_2 \log_e \frac{T_1}{T_2},$$

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$$\text{or}\qquad \underbrace{\frac{L_1}{T_1}(T_1 - T_2)}_{\text{area L}\,+} + \underbrace{(T_1 - T_2) - T_2 \log_e \frac{T_1}{T_2}}_{\underbrace{\text{areas }(K+M) - \text{area M}}_{K}}$$

$$= \quad L \quad + \quad K$$

Mr. Gray's approximate formula was—

$$\text{Work due} = \underbrace{\frac{L_1}{T_1}(T_1 - T_2)}_{\text{area L}} + \underbrace{\left(\frac{T_1 - T_2}{T_1 + T_2}\right)(T_1 - T_2)}_{\text{approximately} = \text{area K.}}$$

This approximate formula only differed from the diagram, and from the formula of Clausius, in assuming that the line joining T_1 T_2 was a straight line. If that were the case the area K would be exactly equal to $\frac{T_1 - T_2}{T_1 + T_2}(T_1 - T_2)$; the whole expression being an approximation within 0·29 per cent. of the true values of K + L, in the case taken by Professor Kennedy with temperatures 831° and 673° (absolute) Fahrenheit. In the Paper J was taken as 770 instead of the more usual 772, which practically neutralized the error, slight as it was.

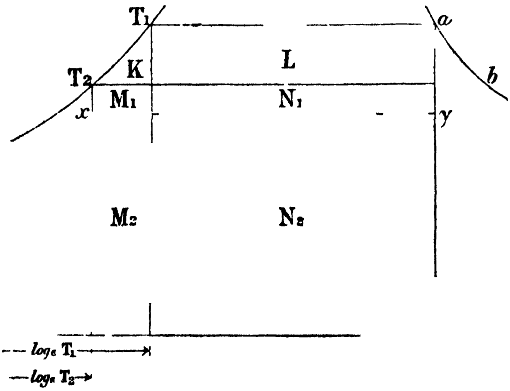
It would be observed that any band of heat, as Q_0 Q_1, &c., added at T_0 T_1 respectively, the band being sufficiently narrow for it to be assumed without sensible error that the heat was all received at one temperature, was divided by the horizontal line $T_2 b$ into heat necessarily wasted, and heat which ought theoretically to be obtained in the form of work; and that the efficiency of any such band of heat was $\frac{T_1 - T_2}{T_1}$, or $\frac{T_0 - T_2}{T_0}$, &c., that being the efficiency of an "elementary engine."

If (instead of, as in the case already considered, where the back-pressure was assumed to be that due to the temperature to which the expansion was carried) the steam was assumed to be exhausted into a vacuum, and the piston allowed to return against a lower back-pressure, a portion of the heat rejected would be converted into useful work, this proportion being the heat equivalent of the pv of that fraction of the original lb. of steam which was present as steam at the termination of the expansion.

The proportion so saved, in the case of an engine expanding to T_2 and exhausting into a perfect vacuum, was represented on the diagram (Fig. 29) by the areas $M_1 + N_1$, the ordinate T_2 being divided at x by the horizontal line xy, in the proportion which the

Mr. Willans. heat equivalent of the pv of steam at T_2 bore to the latent heat at T_2. In the case of an imperfect vacuum, $M_1 + N_1$ would be proportionally smaller.

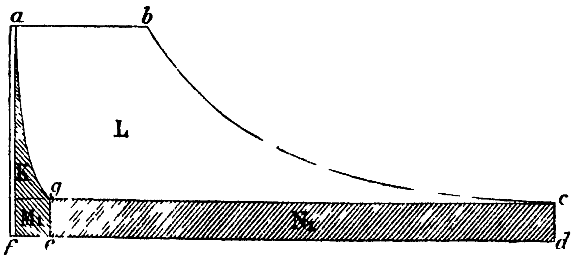
FIG 29



The quantities of heat received and rejected during the Carnot cycle, say between temperatures T_1 and T_2, as shown by Fig. 30, could be most clearly exhibited on the $\theta\ \phi$ diagram. The heat received between a and b (Fig. 30) $= L + N_1 + N_2$ (Fig 29).

The work done during the forward stroke a to c (Fig. 30) = the

FIG 30



whole area of the diagram $a\,b\,c\,d\,e\,f = K + L + M_1 + N_1$ (Fig. 29). Fig. 30 giving the quantities in foot-lbs. and Fig. 6 in heat-units.

The heat rejected between d and e, on the return stroke, namely, up to point where compression begins $= N_1 + N_2$ (Fig. 29), of which N_1 = the work undone during the same portion of the return stroke.

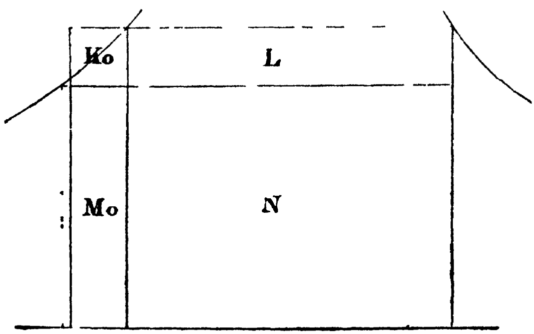
The heat restored to the water by the work of compression $= K + M_1$ (Fig. 29).

Professor Kennedy's three cases could also be readily illustrated by this method. In his first case he took as the standard of work due the area L (Fig. 27) = latent heat at $T_1 \times \frac{T_1 - T_2}{T_1}$, whereas the actual engine ought to give work represented by the areas K + L.

In his second case he assumed that heat, represented by the areas K + L + M + N (Fig. 27), was supplied to 1 lb. of water at T_1 to convert it into steam; that was to say, he supplied, in addition to L + N, which was the latent heat of steam at T_1, heat = h_1 or $K_0 + M_0$ (Fig. 31) = the areas K + M (Fig. 27), which, as had been shown, could not be received by 1 lb. of water at T_1 during the process of conversion into saturated steam.

Thus the work $K_0 + L$ (Fig. 31), taken by Professor Kennedy as

FIG 31.

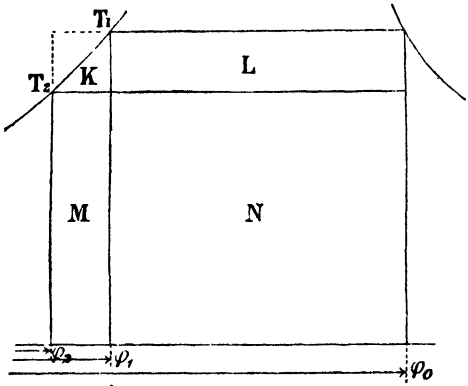


the standard, was the work due, not from 1 lb. of steam at T_1, but from $1 + \frac{K_0 + M_0}{L + N}$ lbs. at that temperature.

In the third case, the heat-weight of the heat supplied at T_1 = $\frac{L + N}{T_1} = \phi_0 - \phi_1$ (Fig. 32). The heat-weight of the heat supplied

Mr. Willans. to the feed-water, at temperatures varying from T_2 to T_1 = $\int_{T_2}^{T_1} \frac{d\,Q}{T} = \log_e T_1 - \log_e T_2$; or on the diagram (Fig. 32), $\phi_1 - \phi_2$. The work due = heat-weight × fall of temperature = $\frac{L+N}{T_1} \times (T_1 - T_2) +$ (approximately) $\frac{1}{2} (\log_e T_1 - \log_e T_2) \times (T_1 - T_2)$,

FIG. 32.



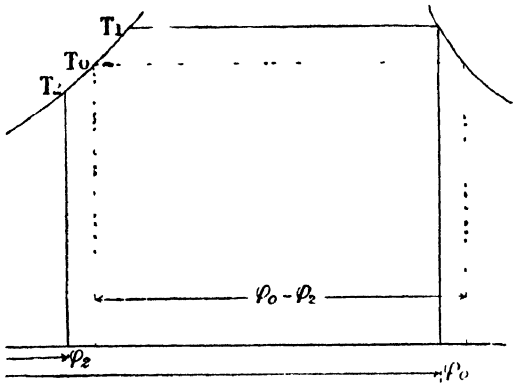
and not as Professor Kennedy gave it $(\log_e T_1 - \log_e T_2) \times (T_1 - T_2)$, which would include the dotted triangular area over K and outside the diagram.

It was obvious that, in the case of 1 lb. of steam used in an "elementary engine," the "heat-weight" could not be the same as in the case of 1 lb. of steam used in an engine where the heat was supplied at various temperatures, if the limiting temperatures were the same; for if the same heat-weight $= \phi_0 - \phi_2$ were taken as the base of the dotted parallelogram on Fig. 33, representing the latent heat supplied to 1 lb. of steam in an elementary engine at T_0, then T_0 must be less than T_1; for the "heat-weight" of the latent heat, supplied to 1 lb. of water in order to convert it into steam, in the case of an "elementary engine" must be (on the diagram) the base of a rectangular parallelogram, and only one such parallelogram could be described with any given base if bounded by the curves of the diagram.

All this might be considered mere hair-splitting; but a practical example lately came under his notice, which showed how important it was to choose accurate standards of comparison. In the technical journals, a few months back, particulars of an engine-trial were given, and it was stated that a non-condensing engine, working

with 150 lbs. boiler-pressure, gave 1 HP. hour per 14·12 lbs. of water evaporated. Now, the heat supplied to the above weight of water, to convert it into steam, taking the feed temperature as that Mr. Wi

Fig. 33.



of the exhaust-steam, was 14,330 units. The heat converted into work per HP. hour = 42·75 × 60 = 2,565 units, or an absolute efficiency of $\frac{2,565}{14,330}$, or 0·179. This was an excellent result, but still one which Professor Perry would consider that of a spendthrift engine; at any rate, it would seem to leave much to be desired. Comparing it with the work due from the Carnot cycle, however, the efficiency would suddenly jump up to 96·2 per cent. of theoretical possibilities, taking the Carnot cycle between the same limits of temperature as unity, a result which no doubt satisfied the experimenter.

If, however, the result was compared with the work due from an ideally perfect steam-engine, namely, with the work represented by the area of the best diagram possible, as given by the formula of Clausius, it would be found that the actual engine gave 103·4 per cent. of the work theoretically possible, or 3·4 per cent. more power than could possibly be obtained from that weight of steam expanded between the boiler and atmospheric pressures. This result would probably, had he realized it, have induced the experimenter to make another trial, after overhauling his indicators and water-weighing apparatus.

He had not been able to do more than give an outline description of Mr. Gray's $\theta \phi$ diagram, in its application to some of the more usual steam-engine problems; but he hoped that it would

Willans. prove as great a help to other practical engineers as it had undoubtedly been to him, and that Mr. Gray might, at an early date, give a more complete description of it to the Institution.

In alluding to the augmented drop (Vol. xciii. p. 280), Professor Perry took a certain weight of water at t_3, and "suddenly immersed it" in steam at t_1, condensing a certain quantity of the steam at t_1, during the process; he then took $w + w_1$, the augmented drop of water at t_1, and "suddenly immersed" it in steam maintained at t_3. This was where Professor Perry's case differed from what actually occurred in steam-engines.

In an expansive engine, such as that under discussion, the drop was not suddenly immersed in the exhaust-steam, but the temperature of the steam in contact with it gradually fell as the expansion proceeded. As the drop fell in temperature, steam was given off from it, and a portion of the steam so given off was condensed, because it did expansive work even as it was formed. The steam so condensed was sufficient to upset the balance and cause accumulation instead of re-evaporation as Mr. Gray had shown. Professor Perry's case was an impossible one in an expansive steam-engine. Mr. Gray's calculation was perfectly correct, assuming adiabatic conditions, and assuming that the drop fell in temperature with the steam surrounding it. These adiabatic conditions could not exist in practice, but he thought that Mr. Gray's hypothesis was much more likely to agree with what actually occurred than Professor Perry's; for it must be remembered that even as the steam was formed, and probably before it reached the surface of the liquid, a part of it was re-condensed.

When the addition due to radiation, priming, and the formation of water during the expansion of the main body of steam was taken into account, he was sure that he had not over-estimated the probable effect of imperfect drainage in cylinders. Mr. Gray's calculation (Vol. xciii. p. 221), and his diagram (p. 222), taking into account the re-condensation of the steam formed as the augmented drop fell in temperature, were well worth Professor Perry's attention; and he felt sure that, when he had given them that attention, he would not continue to think that Mr. Gray's calculation was wrong.

Referring to the foot-note, Vol. xciii. p. 280, "Professor Perry would have more fear in putting forth this adverse calculation were it not that Mr. MacFarlane Gray had used his graphical method to prove another wrong proposition, namely, that the exhaust-steam of Mr. Parsons' turbine could not be superheated;" he could not find a trace of such an argument in Mr. Gray's published remarks;

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but, as he himself had disagreed with Mr. Anderson as to the drying of the steam in the Parsons' turbine, he would try to reply to Professor Perry. Mr. Anderson's remarks were (Vol. xciii. p. 190): "Mr. Parsons had told him a fact which surprised him very much, namely, that although very good duty had been obtained, the steam came out dry." The Parsons' engine was not steam-jacketed; for of course jackets could do no good unless the range of temperature of the metal varied, which happily was not the case in that engine, it being the only one free from such difficulties as initial condensation. If, therefore, as the expansion proceeded, heat was supplied to the steam, it must have been from the steam itself, the heat being possibly, as Mr. Anderson suggested, conducted along the casing or spindle. Such transfer of heat could only take place with a corresponding condensation of steam at the point where the heat transferred was abstracted; and this condensation would have, in the Parsons' engine, the effect of making the exhaust-steam wet, so that, if the condensation due to the work done during expansion were made good in this way, the steam would not come out any drier on that account. If the steam came out dry, very little work could have been done. Take steam at 100 lbs., expanding to atmospheric pressure and remaining dry. To commence with, the heat was supplied at the rate of 1,181·9 heat-units per lb., and the heat in saturated steam at 212° was 1,146·6 heat-units per lb. The heat utilized could only be 35·3 heat-units per lb., and the absolute efficiency would therefore be $\frac{\text{Heat utilized}}{\text{Heat supplied}} = \frac{35 \cdot 3}{1{,}181 \cdot 9} = 0 \cdot 029$. The relative efficiency, or $\frac{\text{work done}}{\text{work possible}}$, would be $= \frac{35 \cdot 5}{139} = 0 \cdot 254$, or 25·4 per cent. He was sure, therefore, that the economy obtained in these engines would not have been obtained if the steam came out dry; and if it were superheated, as mentioned by Professor Perry, it would be so much the worse for the efficiency.

Turning now to the three minor points to which Professor Perry referred:—

1. As to Mr. Gray's approximate formula; he could not speak for Professor Perry's students; but he was sure practical engineers would welcome a formula which avoided the use of Napierian logarithms, and substituted simple arithmetic.

He would here direct attention to one possible misunderstanding, arising from the use of logarithms, which occurred in this Paper, and which, although it would not trouble mathematicians, might confuse many engineers and students. This was, that in the formula

Willans. quoted from Clausius, and used by Professor Perry and Dr. Hopkinson, $U = L_1 \frac{A - B}{A} + (A - B) - B \log \frac{A}{B}$; $\log \frac{A}{B}$ were natural or hyperbolic logarithms. Professor Kennedy gave it correctly $\log_e \frac{T_1}{T_2}$, so that he thought it might be well to notice it.

2. Professor Perry had pointed out that if indicated power alone were considered, and the law of expansion were taken as $p^m v^{m+1}$, the best ratio of expansion would be $r = \left(\frac{p_1}{p_3}\right)^{\frac{m}{m+1}}$, and not $\left(\frac{p_1}{p_3 + F}\right)^{\frac{m}{m+1}}$, as F (the friction) could only come in if brake-power were considered.

He wished to say that, although in the trials he had been mainly concerned to observe the indicated power, yet he had, in all cases, in fixing the number of expansions $\left(r = \frac{p}{25}\right)$, kept well within the number which would have appeared the best, if indicated power alone had been considered to be of importance; and there seemed to him to be no doubt that $\frac{p - 10}{25}$ would denote still more nearly the best ratio in practice. The results of the series of trials given in Table IV seemed to confirm this view. Professor Perry observed, "he was interested to know how the Author arrived at his rule for cut-off." He would refer him to Plate 3, Fig. 2, where the curve showing the number of expansions crossed the work-curve diagonally, at the points where the ratio of expansion $= \frac{p}{25}$; this curve was a little to the left of the best ratio, as shown on the diagram, and a curve passing through the points where $r = \frac{p - 10}{25}$, would of course be still further to the left.

Professor Perry further observed: "Taking simply $p\,v$ constant as the expansion law, then, for the best value, assuming no condensation, $r = \frac{p_1}{p_3}$ or $\frac{p_1}{14 \cdot 73}$, whereas the Author took $r = \frac{p_1}{25}$!" In other words, Professor Perry, taking $p\,v$ = constant, would design an engine with a ratio of expansion = 6·7 for 100 lbs. of steam, while Mr. Willans would give it a ratio of expansion = 4, or less.

But why should $p\,v$ constant be taken? This was the cause of most of the ridiculous ratios of expansion in common use. The designer assumed that the indicator-pencil was going to trace a

common hyperbola: and the point to bear in mind was that if he assumed this, and fixed the ratio of expansion on that assumption, the chances were much in favour of the indicator-pencil doing what he expected. The greater the number of expansions, the more likely was it that the diagram would approach the $p\,v$ constant curve; for initial condensation caused a corresponding re-evaporation towards the end of the stroke, and raised P_3, and unfortunately the designer was apt to regard such a diagram with pride, instead of horror, not realizing that $p\,v$ constant in a diagram was a thing to be avoided.

3. It was for the above reason that he had used a formula $p^6\,v^7 =$ constant; but in a Paper on the condensing trials, on which he was now engaged, he should probably substitute, for the curve obtained by this approximate formula, the true adiabatic expansion-curve. Professor Smith's curves (pp. 158 and 159) were, he noticed, constructed on the supposition that $p\,v =$ constant, and in any practical use which might be made of them this fact should not be lost sight of.

He thought that Mr. Thurston, when he said that a mechanical efficiency of 90 per cent. was to be expected in large engines, had not realized that it was the combined efficiency of engine and dynamo, or $\frac{\text{external electrical HP.}}{\text{indicated power}}$, which was given on p. 37 as 82·3 per cent. The mechanical efficiency of the engine or $\frac{\text{brake HP.}}{\text{indicated HP.}}$ was frequently as high as 92 per cent. in comparatively small engines.

With regard to Mr. Isherwood's contention that the proper units of power were the "total HP.," and the "brake HP.," undoubtedly the brake HP. was the proper commercial unit; but in the Paper he had not been so much concerned with the commercial, as with the scientific side of the question; and the relative values of brake and of indicated HP. varied so much with different types of engines, and also with the size of the engine, that data as to the steam performance of an engine in terms of the brake HP. could have no general value.

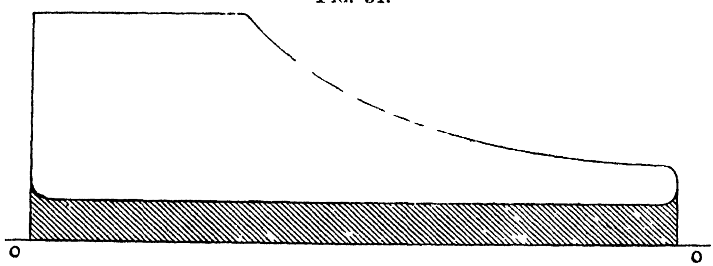
About 92 per cent. of the indicated power, in a fully loaded compound engine of this type, and of average size, say 60 HP., could be obtained in useful work. By fully loaded he meant an engine in which the total indicated HP. developed in the two cylinders (high pressure and low pressure together) was equal to about 40 lbs. mean pressure per square inch on the low-pressure piston area. In such an engine a pressure of about 3 lbs. per

Willans. square inch on the low-pressure piston was required to run the engine *per se*, and as with piston-valves the friction did not increase perceptibly with the load, the relative values of indicated HP. and brake HP. could be readily obtained from the data furnished in the Paper. When worked as a triple engine there was very slighty more friction, and when worked as a simple engine very slightly less.

Mr. Isherwood said "the total HP. gave the philosophic result for the total steam expended." By total HP. Mr. Isherwood meant the HP. obtained by adding the back-pressure, measured to the zero line, to the mean pressure as usually obtained, as shown in Fig. 34.

This method involved more than the usual measurements of diagrams, and the question arose, What was gained by it? Mr. Willans had deducted the atmospheric back-pressure in fixing his

FIG. 34.

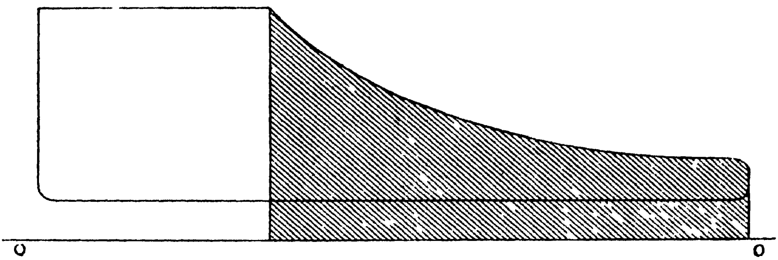


standard of comparison, while Mr. Isherwood added the back-pressure to the power developed according to the actual indicator diagram, instead of deducting it from the standard. He thus added that due to the losses in exhaust-ports, which was one of the causes of loss of efficiency; and in other ways he thought the plan had grave disadvantages. The only absolutely correct comparison was that between steam used, and steam theoretically required, per unit of power. All other comparisons were more or less approximate, and too much reliance must not be placed upon them; while the former comparison was exceedingly easy to make, and absolutely trustworthy. He had used the $p^6v^7 =$ constant in the Paper only as an approximation, and not with reference to thermodynamic efficiency, and had explained why he used the indices six and seven instead of higher ones.

Mr. Isherwood's reasons for calculating the power developed during expansion were:—"When steam was used expansively in a cylinder, the cylinder condensation was the aggregate of two

entirely distinct quantities; one, the condensation due to the work done by the expanding steam, the other the condensation due to the metallic surfaces of the cylinder, including those of the piston and steam passages, and to the changes of their temperature. . . . Hence, of the difference between the weight of steam evaporated in the boiler according to tank measurement, and the weight existing in the cylinder at any point of the expansive portion of the stroke of the piston according to indicator measurement, only the part which remained, after deducting the condensation due to the power of the expanding steam, should be credited to the effect produced by the surfaces of the cylinder, and their changes of temperature. . . . From the foregoing it would be perceived how indispensable, in the analysis of steam-engine performance, was the knowledge of the weight of steam condensed in the cylinder to furnish the heat transmuted into the work of the expanding steam."

FIG 35.



Mr. Willans would point out that the measurement of the area of the expansive portion of the diagram, down to the zero line, could not give this indispensable information with any approach to accuracy.

For the power represented by the shaded portion of the diagram (Fig. 35) was itself the aggregate of three quantities; (1) the power developed by the expansion of the steam shown to be present at cut-off; (2) the power developed by the partial evaporation of water present at cut-off due to the fall in temperature of the steam during the period of expansion; (3) the power developed by the evaporation of a further part of the same water, by the heat given up to it by the cylinder walls during the same period. He was unable, therefore, to recognize the practical utility of Mr. Isherwood's methods, which involved the measuring of the indicator diagram several times, only to arrive at a result which was a very rough approximation. It seemed to him to be

Willans. more to the purpose to compare the area of the diagram drawn with the adiabatic expansion curve, with the area of the actual indicator diagram. To do this, the area of the adiabatic diagram must be calculated, and here he was again obliged to differ from Mr. Isherwood, who said: "The calculation, however, could not be made; it was beyond the reach of mathematics, owing to the continuous condensations and evaporations of expanding steam when doing work, both external and molecular, and even supposing the expansion to take place in a cylinder impervious to heat." He had shown how easily the adiabatic curve could be drawn by Mr. Gray's graphical process; and other methods had also been described by Professor Cotterill and others.

Mr. Isherwood observed that "unexpanded steam was dry and transparent in a working cylinder throughout the whole of the stroke of the piston, suffering scarcely any condensation, no matter how great the difference between the temperature of the entering steam, and the temperature of the exhaust or back-pressure." Mr. Willans had made no experiment as yet on unexpanded steam, and the initial condensation in a cylinder using such steam. He wished to say, however, that even if it always proved to be the case that, under such conditions, the initial condensation was nil, it would not be proved that initial condensation was the result of the higher conductivity of wet steam, and of the consequently greater transfer of heat from the body of the steam to the walls. He thought that, whenever there was a high ratio of expansion, there was a larger retention in the cylinder of the water due to the expansive work of the steam, and that the heating and cooling of this retained water might account for the larger initial condensation undoubtedly observed under such conditions. Although he had no experiments bearing directly on the question, he would give the results of two trials with a triple engine, under precisely the same conditions, except that in the one the engine was exhausting into the atmosphere, and in the other into the condenser (Table, pp. 255, 256). The ratio of expansion was the same in each case, and in the two upper cylinders the initial condensation was very little affected. The steam in the low-pressure cylinder could not be wetter in the one case than in the other, but the initial condensation was enormously increased in the latter case, in consequence solely of the increased range of temperature in the cylinder, and without any increase in the ratio of expansion. He had given the fullest consideration to Mr. Isherwood's views, as the views of one who had devoted many years to the study of these matters, and who had been one of the earliest and most intelligent

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Trial letter, intended ratio of expansion, and intended absolute mean admission pressure		$T\frac{170}{8}$ Condensing.	$T\frac{170}{8}$ Non-Condensing.
Date of trial	1	March 2, 1888	March 9, 1888
Barometric back-pressure (lbs.)	2	14·84	14·49
Boiler pressure above atmosphere	3	170·0	168·7
Cylinder pressure (mean absolute during admission)	4	168·0	164·49
Ratio of expansion (corrected)	5	8·272	7·95
Point of cut-off in h. hp. cylinder	5A	0·485	0·485
" " hp. "	6	0·604	0·604
" " lp. "	7	0·604	0·604
Duration of trial (minutes)	8	176	156
Temperature of engine-room, Fahrenheit	9	55	67
Mean pressure on h. hp. piston	9A	49·33	48·857
" " h. hp. " (under side)	9B	13·166	11·714
" " hp. "	10	20·88	17·37
" " hp. " (under side)	11	6·388	5·107
" " lp. "	12	15·222	11·035
Total mean pressure referred to lp. piston	13	43·702	36·706
" " " cylinder without clearance	14	44·82	37·64
Theoretical mean pressure for corrected ratio of expansion on assumption that $p^6 v^7$ = constant	15	51·87	42·33
Percentage of theoretical mean pressure actually obtained	16	86·4	88·92
Revolutions per minute (mean during trial)	17	402·6	406·2
Indicated HP.	18	37·667	31·919
Feed-water used per hour (lbs.)	19	572·7	578·4
" " indicated horse-power-hour (lbs.)	20	15·20	18·12
" per indicated horse-power-hour accounted for by h hp. indicator at cut-off	21	13·85	16·82
Water theoretically required per indicated horse-power-hour for steam expanded from mean admission to exhaust temperature	22	10·3	14·56
Percentage efficiency	23	67·7	80·35
Lbs. of water collected per hour hp. steam chest	23A	6·0	5·5
" " " " lp. "	24	17·0	15·75
" " accounted for by h. hp. indicator at cut-off	25	522·0	536·8
Lbs. of water accounted for by hp. indicator at cut-off	25A	473·6	486·6
" " " " lp. " "	26	375·9	461·9
" " " " lp. " end of stroke	27	398·9	490·1
Lbs. of water not accounted for by h. hp. indicator at cut-off	28	50·7	41·6
Lbs. of water not accounted for by hp. indicator at cut-off	28A	99·1	91·8
Lbs. of water not accounted for by lp. indicator at cut-off	29	196·8	116·5

Willans.

Trial letter, intended ratio of expansion, and intended absolute mean admission pressure		$T\frac{170}{8}$ Condensing.	$T\frac{170}{8}$ Non-Condensing.
Lbs. of water not accounted for by lp. indicator at end of stroke	30	173·8	88·3
Per cent. of total feed-water missing at cut-off h. hp cylinder	31	8·84	7·19
Per cent. of total feed-water missing at cut-off hp. cylinder	31A	17·3	15·86
Per cent. of total feed-water missing at cut-off lp cylinder	32	34·35	20·14
Per cent of total feed-water missing at end of stroke lp. cylinder	33	30·35	15·26
Heat-units missing per hour at cut-off h. hp. cylinder	34	43,490	35,651
" " stroke " " "	35	1·800	1·462
Initial surface exposed in h. hp. cylinder, square feet	36	1·065	1·065
Temperature Fahrenheit during admission (mean)	37	367·0	365·5
" " reached by cushion steam	38	357·0	353·0
Range of temperature at which initial surface is exposed	39	10·0	12·5
Weight of steam at mean admission pressure, lbs per cubic foot	40	0·3738	0·3665
Surface exposed during admission, square feet	41		
Temperature Fahrenheit during exhaust	42	316·5	317·0
Range of temperature to which admission surface is exposed	43	50·5	48·5
Weight of water in cylinder which at above range of temperature would account for abstraction of heat	44	0·035	0·030

experimenters with steam-engines; but he did not feel that any good end would be served by recalculating all the results according to Mr. Isherwood's methods, as such a course could only tend to confuse. On the other hand, he did not wish to lose sight of the fact, which Mr. Isherwood had pointed out, that it was not always the experimenter who could best interpret his own results; he had, therefore, with a view to facilitating the study of these trials by independent methods, constructed mean diagrams for each of the trials made, and these mean diagrams were given on Plates 7, 8 and 9.

Several other points named by Mr. Isherwood deserved attention. He entirely condemned the calorimeter experiments, and the formula by which the results were calculated. "Many of the formulas regarding the behaviour of steam, so confidently set forth by professors, were just as erroneous as the one in question.

Among them was one employed by the Author to ascertain whether any, and if any, how much water was carried over to the cylinder from the boiler by the steam." Mr. Isherwood observed that the total heat of the steam could only be obtained from it on condition that it was condensed under the same pressure as that under which it was generated; and that, as it was condensed at atmospheric pressure, there was not so much total heat in it then as when it left the boiler. Mr. Isherwood did not explain where the missing heat went to, but simply said that there was a fault of commission in the formula, which credited the steam with all the heat at boiler-pressure. Now the heat could not escape through a pipe which was carefully covered (and Mr. Isherwood's objections would apply equally to a non-conducting pipe), so that there must be a mysterious accumulation of energy somewhere if that view was correct. The explanation was that, in addition to the heat in the steam passing into the tank, there was the heat due to the energy of motion; this was entirely recovered when it reached the tank and reappeared there as heat. The experiment was perfectly sound in principle, and the only possible errors were those of observation. Mr. Isherwood also said: "Further, no provision was made for ascertaining the loss of heat by radiation, or due to the weight, specific heat, and difference of temperature of the material of the tank and the apparatus." This was not correct. The loss of heat by radiation was carefully measured (vol. xciii. p. 153, Plate 4, Fig. 3), and the difference between the specific heat of iron and water was allowed for (p. 152). No reasonable precautions were neglected, and the results were most gratifying, from the fact that the experiments could be again and again repeated with the same result, namely, the substantial agreement of the total heat in actual boiler-steam with the value deduced from Regnault's figures. These remarks applied equally to Professor Smith's objections, who also failed to see that the only place for the heat to go from the boiler was into the tank. Professor Smith preferred to use a wooden tub, and to neglect the heat going into the wood; but surely a wooden tub, saturated more or less with water, would be likely to occasion a larger error than a thin iron tank, the specific heat of which was pretty accurately known. He could quite understand that Professor Smith had "never got reliable results so long as only a small quantity (20 lbs.) of cold water was used;" but he could not understand how trustworthy results could be obtained with ½ ton of water if the heat passing to the saturated wooden sides of the tub were neglected, unless indeed (as was implied) he had taken the heat entering the tank

Willans. with the steam as being the total heat of the steam "less the area of the whole indicator diagram, obtained by its evaporation and expansion, down to atmospheric temperature," when one error might possibly balance the other. Mr. Isherwood had observed that the cost of steam was not the same at various pressures, and that the efficiency of the boiler varied with various pressures. Mr. Willans had not considered it desirable to complicate the Paper, which simply dealt with the efficiency of a steam-engine, and the use which that engine made of 1 lb. of steam at various pressures, and under various conditions, with considerations which more properly belonged to the question of boiler efficiency; but the slight extra cost of high-pressure steam could be readily allowed for. To the objection that although a given engine might develop power more economically when running at double the speed, and the same mean pressure, yet that did not of itself prove that high-speed engines were more economical than low-speed ones, where a given power was required, he might observe that, so far as initial condensation was concerned, the figures in the Tables appeared to show that this was the case; for the abstraction of heat per unit of time by initial condensation in a cylinder the size of the low-pressure cylinder used in the trial, when working at 200 revolutions per minute, would evidently be greater than the corresponding loss in a cylinder the size of the high-pressure cylinder, when working at 400 revolutions, while the power developed in them would under those conditions be the same. The further advantage of using an engine of half the size for the same work did not come within the province of the Paper, but it was sufficiently evident. Professor Dwelshauvers Dery had observed that "the lack of exchange of heat" between steam and metal was not "ideal, and not even desirable for the economical use that man made of the machine. In fact, during expansion, the metal could usefully restore all, or a portion of the heat that it had absorbed from the steam during admission." This might be understood to mean that there was no harm in the heat passing from steam to metal, and afterwards during expansion from metal to steam; but he was sure that Professor Dery did not mean that. Granted a certain amount of initial condensation, any heat so lost which came back during expansion was a gain, and the earlier it came back the greater was the gain; but the highest efficiency, other things being equal, would be found in the engine which most nearly approached adiabatic conditions; for the heat which came back always came back late, and generated low-pressure steam instead of high-pressure steam. The perfect expansion-curve was the

adiabatic curve, and in that sense it was the theoretical expansion-curve, which could be most nearly approached in high-speed engines, and in engines where the range of temperature was small. Where jackets had proved advantageous, it would be found to be because they prevented (by drying the walls) the exchange of heat between metal and steam, or because they prevented the accumulation of water, and a similar exchange of heat between that water and steam; and not because of any advantage derived from heat imparted to the cylinder steam by that in the jackets. Mr. W

Sect. II.—OTHER SELECTED PAPERS.

(*Paper No. 1399.*)

"The Mount Washington Railway, New Hampshire, U.S.A."

By Otto Gruninger.

(*Abstract.*)

Mount Washington is the highest of the White Mountains in the State of New Hampshire, and bears about the same relative importance to the mountains of the United States that the Rigi[1] does to those of Europe. Many years ago an excellent highway was constructed on the east side of the mountain from Gorham, the nearest railway station, to the summit. The great success of this road, and the constantly increasing throng of tourists, led to the enterprise now to be described.

The inception of the Mount Washington Railway dates from 1857, when Mr. Sylvester Marsh, its designer and constructor, first applied to the State Legislature of New Hampshire for a charter, at the same time exhibiting a model of the rack and locomotive proposed. The scheme was, however, regarded as the dream of a madman, and it was not till oft-repeated applications had wearied out the opposition, that the necessary powers were obtained. On obtaining his charter, Mr. Marsh took out patents for: (1) The construction of an improved central rack; (2) A specially-designed locomotive; (3) an entirely new brake-mechanism.

The construction of the line was begun in the summer of 1866, was continued during the summers of 1867 and 1868, and was completed in 1869, in July of which year it was opened for traffic. The success of the work induced the construction of many similar lines in Switzerland and Germany, but though furnished with an improved form of rack and built more substantially, these lines

[1] This description was originally written in German for the information of Mr. N. Riggenbach, who contemplated the construction of a similar line up the Rigi from Vitznau. The MS. passed through the hands of the late Mr. W. W. Evans, M. Inst. C.E., who had a translation made, which is now in the library of the Inst. C.E. From this original the present abstract has been prepared. Some additional particulars derived from other sources have been interpolated.

do not differ in principle from the prototype which forms the subject of this Paper.

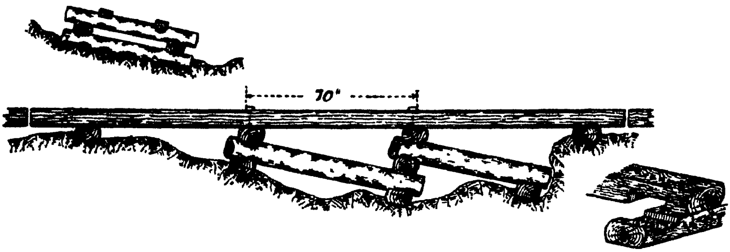
It leads to the top on the west side of the mountain, whence a country road communicates with Littleton, about 20 miles distant.

The dispositions decided upon for the profile and plan of the line were that the maximum grade was not to exceed 1 in 3, and the minimum radius for the curves was to be 500 feet. These principles once adopted, Mount Washington did not offer peculiar difficulties to the construction of the railway. There are no viaducts or bridges; a small brook flowing within 200 feet of the starting-point of the road was crossed by ordinary trestles; earthworks were reduced to surface-scraping and a few insignificant cuts. There are no embankments, wooden structures being used in their stead. At about two-thirds of its height the mountain is covered with pine forest; through this the line passes. For 50 feet on each side of the road the wood was cut down (partly burned down) to get the necessary building material and to make room. The timber as long as it stood was almost valueless, as the land could have been bought at $2 per acre. A small steam saw-mill was erected at the foot of the mountain for shaping the timber, and several log-houses were built for the accommodation of the men engaged in constructing the line. All timber and other materials were carried uphill by the locomotive as fast as the line advanced. Three distinct forms of substructure were adopted, varying with the natural formation of the ground. By each of them, two lines of longitudinal ties or timbers, to which the sleepers were attached, were securely connected with the road-bed below, so that in no case could a downward slipping along the line occur. The average cross-section of these longitudinal timbers is 10 inches by 12 inches, and their length about 50 feet. Where the line of road was even and the ascent uniform, the surface gradient was accepted without change. Strong half-round cross-ties, the faces roughly hewn, were embedded in the earth, and the longitudinal timbers were set in slightly, being securely fastened to the cross-ties with iron bolts. A second mode of construction was adopted where the ground was somewhat irregular (Figs. 1); and where in an ordinary railway embankments would have been necessary trestle-work (Figs. 2) was used. Cross-sleepers, 8 inches by 6 inches in section were laid on the upper timber of the substructure (Fig. 3), and to these sleepers are attached the longitudinal stringers, which carry the outer rails and the central rack.

The most important part of the superstructure is the rack (Fig. 4). It consists of two 3-inch iron angle-bars connected by

the cogs themselves. The latter are circular in section, made from the best wrought-iron. On a 4-inch length, shoulders were turned

Figs. 1.



Figs. 2.

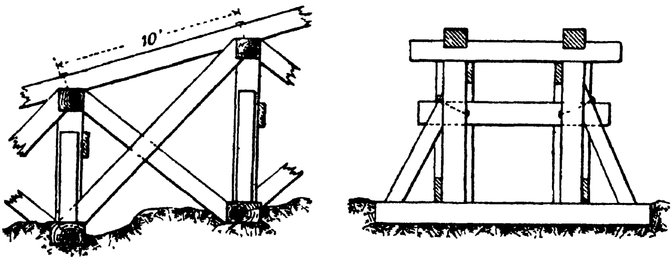


Fig. 3.

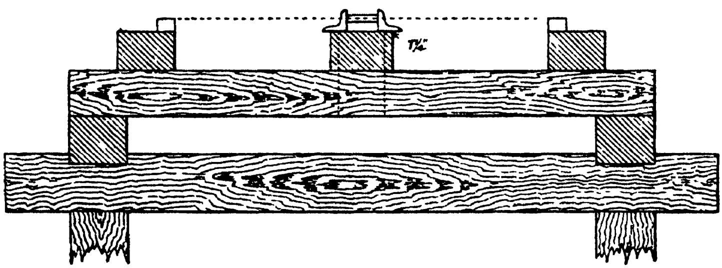
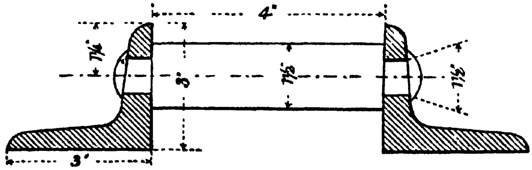


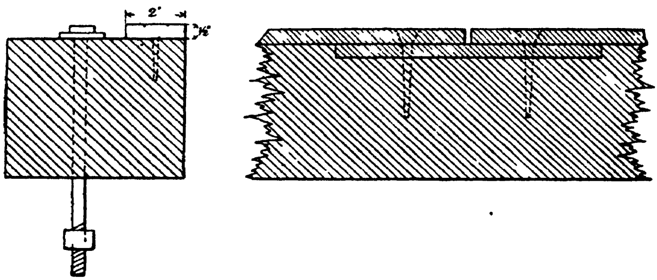
Fig. 4.



so as to butt against the angle-bars, having a pin on either $1\frac{1}{8}$ inch in diameter and of a length sufficient for cold riveting. The cogs

were not subjected to any special finish, but were used in the same state as delivered from the rolling-mill. The round holes in the angle-bars were punched. The length of the different rack-sections was originally fixed at 12 feet; but in consideration of the expansion of the iron it was afterwards altered to 10 feet. The outer rails (Figs. 5) were flat iron bars. At every 2 feet they were drilled and countersunk to receive the wood-screws by which they were attached to the longitudinal timbers. Under the joints, which were alternate, wrought-iron chair-plates were let into the timber, to take the bearing of the rail-ends and so prevent the latter from being pressed into the timber. This form of rail was adopted on account of its cheapness. It has since been superseded by a flange rail weighing 30 lbs. per yard.

Figs. 5.



The horizontal flange of the angle-bar forming the sides of the rack projects $1\frac{1}{4}$ inch beyond the wooden stringer on which the rack rests. The projecting lower surface forms a track for a safety apparatus connected to the engine in such a way that the cog-wheel on the driving-axle can never lose contact with the rack. The rack is securely fastened by bolts which pass through the stringer carrying it, and through the cross-sleepers. All the bolts are $\frac{3}{4}$ inch in diameter. The Boston Machine Company took the contract for all the ironwork at the following weights:—

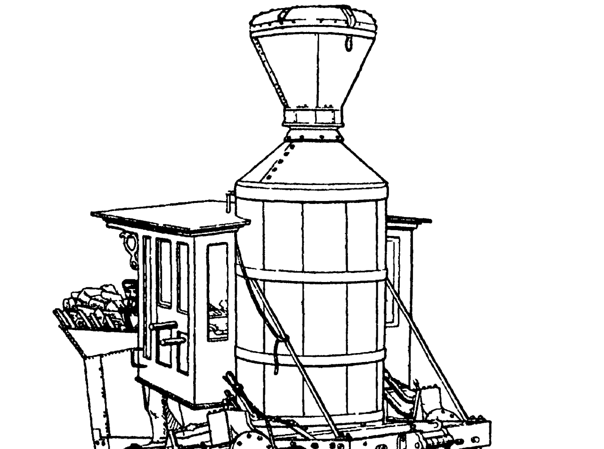
Rail per lineal yard	60 lbs.
Flat bars for rails	21 „
Bolts	9 „
Total	90 lbs.

at $9 per lineal yard of track, with a proviso to furnish 1 mile a month, if necessary. In order to obviate an alteration of pitch at the joints of the rack by changes of temperature, iron wedges were driven between the ends of the section. The object was

accomplished, but the rack was now forced to bend itself in wave lines, the deflection amounting to about $\frac{1}{8}$ inch in a distance of 3 feet 4 inches. These deflections, however, had no influence on the motion of the locomotive.

Engines.—At the opening of the line there were two locomotives. The early engines (Fig. 6) had vertical boilers, supported on a platform carried by wheels of unequal diameter, so to be horizontal at the average gradient of the line. The differences of inclination on the various sections of the line did not materially affect the water-level in these engines. The height of the cylindrical portion

FIG. 6.



of the boiler was 10 feet; diameter of the boiler-shell was 4 feet; of the fire-box, 3 feet 3 inches; height of fire-box, 3 feet; of steam space, 2 feet 6 inches; number of tubes one hundred and seventy-eight; inside diameter of tubes, $1\frac{1}{2}$ inch; average steam-pressure from 70 to 80 lbs. per square inch. The smoke-stack, of the old petticoat form, reached to from 14 to 15 feet above the foot-plate. The cylinders were 9 inches in diameter with a stroke of 12 inches. Each cylinder had only one eccentric for forward motion, that for backward motion and the whole link mechanism of ordinary locomotives being dispensed with. The motion of the eccentric was $2\frac{1}{2}$ inches, and the valves were set to cut off at about two-

thirds stroke. Different degrees of expansion were thus impossible, but the power and speed required on a line of this description were found to be almost constant, so that but little inconvenience resulted. The engine has, of course, a constant tendency to go down hill, and would be precipitated in that direction with enormous velocity were it not controlled by ample brake-power. The braking is performed by the compression of air on the principle of the counter-pressure steam-brake. The forward eccentric working the valve, the cylinder acts like a pump drawing in air, compressing it and finally ejecting it. For manipulating this brake a globe valve is used, by which the driver is able to accelerate or retard the motion or to bring the train to a dead stop in its own length. The heat developed in the compression of the air has no bad influence on the pistons or cylinders. At intervals the latter are lubricated with oil. The application of this mode of regulation presupposes that the gradient of the road at no place falls below the limit at which the gravity of the engine exceeds the resistance to down-hill motion. To meet this Mr. Marsh fixed the minimum gradient at 1 in 15. In addition to the air-brake three other brakes are arranged on the rear axle, a ratchet with detent, and two band-brakes. The former is a cog-wheel gearing into the rack, but differing from the driving-wheel in size and material, being of cast-iron. This wheel serves as a ratchet, a strong detent preventing by its play any downward motion when the engine is going up hill. It is only used in case of emergency. On the same axle, close to the bearing-wheels, are the band-brakes. The diameter of the drum carrying the brake-strap is 2 feet, the width of the strap 4 inches. From one arm of a bell-crank, to the other arms of which are attached the ends of the band, a chain is carried, winding round a vertical shaft, projecting through the foot-plate, and terminating in a handle at the driver's side. Turning the hand-wheel winds up the chain and applies the brake. The effect is almost instantaneous, and notwithstanding the low speed the train is brought up with a sudden shock. Finally, a safety-apparatus prevents the driving cogwheel becoming ungeared from the rack. Two strong iron straps, bent to the shape of a truncated **V**, are attached by the upper flanges to the framework of the engine in such a way that one V-piece hangs down on either side of the driving-wheel. To the truncated portion of the strap is attached a system of rollers, one vertical, arranged so as just to clear the under part of the overhanging end of the rack (Fig. 3, p. 262), and two horizontal to prevent rubbing contact with the sides of stringer to which the rack is attached. A small grease-pot is fastened to the

under side of the framework with a leaden pipe leading to the cogs of the driving-wheel. Tallow is the lubricant used, the heat radiating from the engine keeping it liquid. The quantity allowed to drop on the teeth of the wheel is regulated by means of a small cock.

The tender is simply a wooden box made of 1-inch boards for carrying fuel, the water being contained in a sheet-iron reservoir under the floor of the engine. The weight of the first engine put in service so loaded was 6 tons, and when working under normal conditions it took two hours to push 6 tons to a height of 3,600 feet from the starting-point. The second and third engines climb the mountain in one hour and a quarter, including stoppages for taking in water. About three-quarters of a cord of wood is consumed every trip. Several important modifications were introduced into the third engine built. The four bearing-wheels are of equal diameter; the foot-plate is fixed at an inclination corresponding to the average gradient, the driving cog-wheel is transferred to the rear axle where the weight is greatest, also the safety-apparatus for preventing the cog-wheel from ungearing has been simplified, the rollers being dispensed with, and the apparatus only coming into action in case of an actual lifting of the cogs out of the rack.

The rolling-stock is of the character since become well-known on mountain railways, and therefore does not need detailed notice. The seats of the passenger cars are pivoted and fitted with adjustable backs so as to take a horizontal position on any gradient. Each car has two rows of benches, one on each side, with a central passage down the middle. A band-brake, ratchet and detent, and two air-brakes, are fitted to each car. In the later cars some modifications have been introduced, the central passage has been abolished, and the seats occupy the whole width of the car, and egress is at the side, as in an English railway carriage.

There are no points and crossings on the line, turn-tables being fixed at the top and bottom of the mountain.

The cost of the entire line, 3 miles long, to the time of opening was about $90,000; but for some years afterwards all the profits were devoted to improving the track and rolling-stock, so that the railway in efficient working order, with new permanent way and all the improvements suggested by the first few season's working, absorbed nearly $200,000 dollars, or say £40,000.

The Paper contains a mathematical discussion of the different

elements of the rack system, and is illustrated by forty-three sketches in the text, and by a series of photographs from which Figs. 1–6 have been prepared.

[Note by the Secretary Inst. C.E.—The foregoing description, written twenty years ago, is now of little more than historical interest, the permanent way and rolling-stock of the Mount Washington Railway having been since almost entirely remodelled, with the result that little of the original work except the road-bed now remains. It is, however, deemed appropriate to record in these pages some particulars of the first mountain railway worked by rack-and-pinion, the work of Sylvester Marsh, a man of singular tenacity of purpose, who had to struggle against great difficulties in the execution of his cherished design, and whose name has not been generally associated with the rack system.]

(*Paper No. 2360.*)

"Multipliers and Curves for ascertaining the Discharge, &c., at various Depths in the same Sewer."

By Robert Maynard Gloyne, Assoc. M. Inst. C.E.

The design and construction of sewers, and rules for calculating their velocities and discharges, have been repeatedly and exhaustively dealt with; but the Author has, time after time, felt the want of some simple method of finding these quantities in the same sewer at different depths, without having to make repeated and vexatious use of the same formulas. Anything tending to simplify such calculations, which are hourly coming before the Civil Engineer, will be of interest, and, it is hoped, of practical value.

It occurred to the Author, in the course of making numerous and hurried calculations of this nature, that there must be some ratio between the discharge, velocity, hydraulic mean depth, area, and wetted perimeter at different depths in the same sewer; that is to say, taking the discharge for instance, this must, at any depth, bear a certain fixed proportion to that at any other depth. The idea was examined, sifted, and investigated in a practical manner, the result being the present Paper and accompanying diagrams and Tables, Plate 10.

The calculation for the five factors being easy when the sewers are running full, and this depth being the most convenient, it was taken as the standard, and the value of each factor, at the different depths, has been expressed in decimal parts of that standard.

In the case of circular sewers (Figs. 1 to 6), a section of a culvert 10 feet in diameter was divided throughout into depths of 6 inches, and each of the five factors was calculated at every segment of the circle, the fall of course being constant. In the case of egg-shaped sewers (Figs. 7 to 12), a section of a culvert 10 feet high by 6 feet 8 inches wide was dealt with in precisely the same manner. The results, in each case, were noted down, and, by dividing the value of each factor at the different depths by that of the same factor due to the full depth, a set of figures was obtained, which,

when plotted on ordinates representing the different depths, produced a curve for each factor.

It will be noticed that the section of the egg-shaped sewer corresponds to the "old form," the transverse diameter being equal to two-thirds the depth, the radius of the invert equalling one-fourth of the transverse diameter, and the radius of the sides being equal to the full depth.

The Figs. have been deduced from calculations obtained by using the formulas generally accepted in dealing with sewers, namely,

and $$D = V \times A,$$

in which $V =$ the velocity in feet per minute; $f =$ the fall in feet per mile; $r =$ the hydraulic mean depth, or area divided by wetted perimeter; $D =$ the discharge in cubic feet per minute; and $A =$ the area of the flow. The horizontal figures at the bottom of Figs. 1 to 5, and 7 to 11, inclusive, represent the values of the different depths expressed in decimal parts of that of the full depth, this being taken as unity. In a similar manner, the vertical figures at the tops of the tables, numbers 1 to 5 and 7 to 11 inclusive, represent the values at the different depths of each factor, expressed in decimals of its value calculated for the full depth, this being also taken as unity. The Tables, Figs. 6 and 12, are a condensed statement of Figs. 1 to 5 and 7 to 11, for their respective form of sewer, from which the value of either factor at any depth can be easily and readily ascertained.

In examining the curves, it will be noticed that those for area and wetted perimeter increase continually to the full depth in both forms of sewer; that those for hydraulic mean depth and velocity attain their greatest value in the circular sewer at 0·80 of the full depth, and in the egg-shaped sewer at 0·85 of the full depth, in both cases being considerably greater than at the full depth; and that those for discharge in both cases reach the highest point immediately before they end. This shows that a circular or egg-shaped sewer running full is not discharging to its full capacity.

This statement will, at first, appear paradoxical; but, on closer investigation, it will be seen that there is nothing strange in it. The discharge includes the other four factors, so that, in considering this matter, each must be separately dealt with. Referring to the Figs. and Tables, it will be seen that, although both the area and the wetted perimeter, which make up the hydraulic mean depth, attain their greatest value when the sewer is full, the increase in

the value of the wetted perimeter is much more rapid towards the end than that of the area; consequently, the resulting hydraulic mean depth is less than when the difference in the values of the two factors is greatest in favour of the area. This, of course, entails a reduced velocity, and consequently a less discharge than when a greater velocity is multiplied by a slightly less area. In addition to simplifying calculations for velocity and discharge, the Tables will be most useful in determining the depth of flow in any sewer due to a given discharge, and the heights of weirs and storm overflows.

The following examples will illustrate the method of using the Tables:—Suppose it be required to know the discharge, &c., of any sewer at a given inclination at various depths of flow. Instead of having to make separate uses of the same formulas for each depth, it is only necessary to obtain by them the discharge, &c., when full, the required information at the other depth being obtained by multiplying the value so found by the vertical figures at the top of the Tables, which correspond to the depths at which the information is required.

Example:—Required the discharge of a culvert 10 feet in diameter, at a fall of 2 feet per mile when running one-quarter and three-quarters full. By formula, the discharge when full is found to be 13,658·89 cubic feet per minute, and this value, multiplied by 0·148 for the quarter, and by 0·882 for the three-quarters, will give the required information:—

$$13{,}658\cdot 89 \times 0\cdot 148 = 2{,}021\cdot 53$$
$$13{,}658\cdot 89 \times 0\cdot 882 = 12{,}047\cdot 14$$

cubic feet per minute corresponding to the respective depths. Again, suppose that it be required to know the depth to which discharges of 2,021·53 and of 12,047·14 cubic feet per minute will respectively fill the same sewer, or the heights of the weirs necessary to stop and turn these discharges, the one operation giving either or both results. Having obtained, by formula, the discharge when full, it is only necessary to divide the given quantities by that value, and to find the ordinates corresponding to these results, at the feet of which are the depths required. For instance, 2,021·53 ÷ 13,658·89 = 0·148, and tracing the ordinate corresponding to this to its foot, a value 0·25 is found, thus giving a depth due to the assumed flow, or a height of weir necessary to turn that flow, of one-quarter the full dimension, namely, 2 feet 6 inches. Similarly, dividing 12,047·14 by 13,658·89, a result 0·882 is obtained, and again tracing the corresponding ordinate

to its foot, a value 0·75 is found, giving a depth of flow, or height of weir, of three-quarters the full dimension, or of 7 feet 6 inches.

Thus, by the employment of these Tables in such calculations, the repeated use of the same formulas is obviated, and a considerable amount of time gained.

The Paper and Tables are submitted as a continuation of those on the "Discharges of Circular and Egg-form Sewers," by Mr. W. T. Olive, Assoc. M. Inst. C.E.[1]

The Paper is accompanied by two sheets of illustrations, from which Plate 10 has been engraved.

[1] Minutes of Proceedings Inst. C.E., vol. xciii. p. 383.

(*Paper No. 2380.*)

"Utilization of the Motive Power of the River Rhône at Geneva."

Compiled by Henry Handley Pridham Powles, Assoc. M. Inst. C.E., from official documents of the City of Geneva.

A few years ago the authorities of the City of Geneva determined to make use of the waters of the river Rhône for obtaining motive-power for pumping, electric lighting, &c. A part of this motive-power had already been applied for various industrial purposes, but only a very small fraction of the enormous power available. An elaborate report, and a programme of what they intended to carry out, was prepared by a technical sub-committee, and approved of by the Administrative Counsel of the city. Prizes were offered to makers of turbines and pumps for the best arrangement, the authorities reserving to themselves the right to adopt any one of the plans, wholly or in part.

Four firms competed, one American, and three Swiss. The first prize was awarded to Messrs. Escher, Wyss and Co., of Zurich, and to this firm the carrying out of the work was entrusted. The following is an abstract of the programme drawn up by the authorities:—

Art. 1.—The proposed works to consist of—

a. Turbines worked by the fall of the Rhône at La Coulouvrenière.

b. The transmission of the power from the turbine-house to the manufactories where the power will be used.

c. Discharge-sluices.

The authorities reserve the right to divide the contract into different parts, or to give the same to such constructors as they think fit, without competition.

Art. 2.—The left branch of the Rhône will be made use of as the supply-canal, and this canal will be extended from the point de l'Ile as far as the turbine-house by means of a dam. A small turbine can be placed in this dam to work the sluices.

Art. 3.—The turbine-house should be about the same level as the Place de la Volontaires, from which place access to it will be obtained. The authorities desire attention on the part of the competitors to the possibility of placing the turbine-house in a continuation of the Quai de la Porte; also, as the appropriation of

existing buildings may prove too costly, they ask the competitors to consider another plan, namely, to place the turbine-house in the canal.

With the exception of these observations the competitors are left entirely at liberty as to the disposition of the buildings. Attention is drawn to the following points:—

1. The turbines should be so arranged that the power can be transmitted, in the simplest manner possible, to the existing works on the banks of the river.

2. The construction and arrangement of the buildings should be such that they may be readily extended, and more turbines added.

3. The discharge-sluices to be arranged so that they may be sufficient for the whole number of turbines for the first period of the work to be carried out, and to allow of the surplus water not flowing through the turbines to pass away. The total quantity of water flowing down the left branch of the river may amount to 12,250 cubic feet per second. In case the authorities find that the schemes proposed by the competitors are too costly, they will demand less costly schemes.

Art. 4.—The system of turbines is left to the competitors, but they should give a detailed explanation of them, and a reference to any installations they may have already carried out. Each turbine should be provided with a regulator.

The transmission of the power should be studied for the four cases—

a. Transmission direct, by a crank-plate and connecting-rods, to pumps.

b. Transmission by low-speed horizontal shafts driving-pumps.

c. Transmission by high-speed shafts driving electric-machines.

d. Transmission by wire-ropes.

Art. 6.—It is proposed to begin with an installation capable of exerting a force of 1,200 HP. gross, and to provide motors for two-thirds of this amount.

Art. 7.—The volume of water, the fall, and the gross power at disposal for working the motors, are given in the Table below:—

FIRST STAGE of the FIRST PERIOD.

	Volume of Water in Cubic Feet per Second.	Fall in Inches.	Gross HP.
Low water	1,765	114	1,907
High water . . .	2,825	71	1,894

In the second stage of the first period the quantity may be taken as 3,531 cubic feet per second.

SECOND PERIOD (a further development of the scheme of utilizing the motive power).

	Volume of Water in Cubic Feet per Second.	Fall in Inches.	Gross HP.
Low water	4,238	146	5,872
High water . . .	9,428	67	5,850

The level of the sill of the supply-canal, or head-race, will be 207 inches below the bench-mark on the stone of Niton; the level of the sill of the discharge-canal, or tail-race, will be 342 inches below the same bench-mark. This bench-mark is the point of departure for the levelling of Switzerland, and is 1,235 feet 7 inches above the level of the sea; in the reports it is represented by the letters R. P. N.

Art. 9.—The work is divided into three heads. The first comprises the motors; the second the transmission-gear; the third the sluices.

All the necessary tools, &c., for the daily manipulation of the machines to be provided under each head.

Art. 10.—The contractors to give carefully-dimensioned plans, elevations, and sections, with sufficient detail to enable the nature of their proposals to be understood; a specification giving the approximate weight of the different parts, as well as the contract-price of that which falls under the first and third heads, and a price per kilogram of the transmission gear.

The remainder of the programme is taken up by a recital of the penalties, mode of payment, responsibilities, &c.

Messrs. Escher, Wyss and Co., sent in two different schemes, one of which was accepted; an abstract of their amended specification is here given.

Turbines.—A reaction turbine on Jonval's system, with a sluice over the distributor or guide-blades, calculated for: 1stly. A fall of 12 feet 1$\frac{5}{8}$ inch net, and a volume of water 211 cubic feet per second. 2ndly. A fall of 5 feet 6$\frac{5}{8}$ inches net, and a volume of water 471 cubic feet per second; the effective HP. in both cases to be 210.

A cast-iron foundation-plate for carrying the footstep, the dis-

tributor, with three rows of guide-blades (in two halves), sluices over the two inner rows of guide-blades, and the gear for working it; an intermediate bearing for the turbine-spindle, the turbine-wheel in two halves, the hollow turbine-shaft, and the solid inner shaft with steel pivot; the column for the footstep, the footstep-box, of cast-iron bashed with lignum vitæ; the steps of the intermediate bearing of lignum vitæ, the other steps of bronze and white metal. Weight of the whole, about $29\frac{1}{2}$ tons.

Pumps.—Two horizontal double-acting pumps, coupled at right-angles to a crank-pin in a crank keyed to the top of the upright turbine-spindle, working at high- and low-pressure.

1. For low-pressure, each pump with a piston $16\frac{7}{8}$ inches diameter, stroke 3 feet $7\frac{1}{4}$ inches, working at 26 revolutions per minute, and capable of raising 3,432 gallons per minute, against a pressure equivalent to a weight of 164 feet.

2. For high-pressure, each pump with a piston $12\frac{1}{4}$ inches diameter, stroke 3 feet $7\frac{1}{4}$ inches, working at 26 revolutions per minute, and capable of raising 1,723 gallons per minute against a pressure equivalent to a height of 328 feet.

The pumps are fixed to an angle bed-plate of cast-iron; this plate also carrying the top-bearing of the turbine-shaft and the guides for the piston-rod crossheads. The estimate includes two high-pressure pump-barrels and pistons, and two low-pressure pump-barrels and pistons, eight valve-boxes and valves, all the necessary stuffing-boxes and glands, two piston-rods, two connecting-rods, crank and crank-pin, and all the necessary lubricators, air-cocks, &c. Total weight, $44\frac{1}{4}$ tons.

Air-vessels for the Pumps.—Two vacuum-vessels on the suction-pipes, all the connecting-pipes and suction rose, the support for the lower part of the air-vessel on the delivery-pipe, the necessary connecting-pipes from pumps to main for low- and high-pressure, two sluice-valves of $23\frac{5}{8}$ inches opening, a safety-valve; the upper part of the air-vessel of steel-plate, riveted; indicators to show the level of the water in the air-vessel; iron ladder, and sundry fittings. Weight, about $32\frac{1}{2}$ tons.

Supply-valves.—A double supply-sluice, with strong iron framing above the turbine, with screw and necessary gear; total width of sluices, 18 feet. Weight, about 6 tons. Price per ton, £31. A small motor for working the supply.

Sluices.—A small tangential turbine on horizontal axis, with connecting-gear for opening and shutting the sluices. Price, £58.

Strainers.—A strainer of iron bars, riveted and bolted, one hundred and fifty iron bars; width of strainer, 22 feet 11 inches;

length of bars, 20 feet 8 inches; depth of water, maximum, 12 feet 7 inches. Weight, about 6 tons.

An angled strainer in front of the first turbine of the installation, with one hundred and forty-five bars of a mean length of 10 feet 4 inches each, with framing and supports. Weight, about 3 tons.

Discharge-sluices.—Framework of iron, and gearing and fittings for twelve discharging-sluices, each 9 feet 10 inches wide, and for a maximum depth of water of 12 feet 10 inches. Weight, about $44\frac{1}{4}$ tons.

A small motor with tangential wheel, with horizontal axis to open and shut the discharge-sluices.

ZURICH, *August 6th*, 1883.

Estimate for the four Air-Vessels with Pressure-regulator.

Four air-vessels of plate-iron, with domed top, each 4 feet 11 inches diameter and 39 feet 4 inches high, calculated for a pressure of 147 lbs. per square inch, and proved to a pressure of 221 lbs. per square inch; each vessel in two parts, to be riveted together when in place. Weight (total) about $35\frac{3}{4}$ tons.

Fittings, pipes, and sluice-valves for the four air-vessels, the sluice-valve of $15\frac{3}{4}$ inches opening; manhole-covers, &c. Weight, about 19 tons.

A pressure-regulator, by accumulator and safety-valve. Weight, about $3\frac{1}{2}$ tons.

Remarks by the Experts on the various schemes for Utilizing the Motive Power of the Rhone at Geneva.

From the examination of the different schemes, it is evident that the principal problem to be solved is the establishment of machines for raising water in the best and most rational manner. The distribution of force by cables (tele-dynamic), is most probably limited to a small part of the force, for which one turbine will suffice for a long time to come.

With respect to electric lighting, the most rational means of working the electric machines will be by turbines at the electric-lighting station, worked by the water distributed under pressure.[1]

Under these conditions, the question resolves itself into two heads:—

1. To consider whether preference should be given to a high pressure, equivalent to a head of 328 feet, which would be more economical than a lower pressure now in use, equivalent to a head of 164 feet.

2. The adoption of turbines of 206 HP., in preference to turbines of 137 HP., as fewer will be required in the former case, and a saving in the number of chambers (one for each turbine), fifteen in the former, and twenty in the latter case.

The volume of water flowing through each turbine of 206 HP., with a fall of 5 feet 6⅛ inches, is 471 cubic feet per second (maximum). The chambers should be 18 feet to 19 feet 8 inches wide, and the depth of water from the lower plane of the revolving wheel, 8 feet 2½ inches. The speed of the effluent water is from 3 feet 2¼ inches to 2 feet 11 inches per second, and the corresponding loss of fall, from 2 inches to 1¾ inch.

The continuation of the report contains remarks on the regularity of the pumps, and is accompanied by some sections of the embankments and dams necessary to guide the water to the turbine house.

The works here set forth were begun in 1883, and having since been completed by Messrs. Escher, Wyss and Co., in accordance with the foregoing conditions, are now in active operation.

Plate 11 shows the site of the works, and also gives an elevation of the engine-house, and details of the machinery.

(*Paper No. 2331.*)

"Stress-Diagrams of Solid Structures."

By Professor Robert Henry Smith, Assoc. M. Inst. C.E.

So far as is known to the Author, the modern graphic method of finding stresses has been applied to flat structures only, although, so long as the method is thus restricted, it deals incompletely and imperfectly with actual problems. No structure can have sufficient lateral stability against lateral forces unless its lateral dimensions be large in proportion to these upsetting forces. The two side-girders of a bridge stand only because they are connected by cross-girders and wind-bracing. Every engineering structure of importance must be treated as a solid structure, in order to arrive at a true knowledge of the stresses acting throughout it.

The more important mathematical differences between the two-dimensional and the three-dimensional problems are as follow :—

If l represents the number of links and j the number of joints, then, in a flat, stiff, but non-redundant structure, the relation between these numbers is

$$l = 2\,j - 3.$$

In a solid, stiff, but non-redundant structure, the corresponding relation is

These rules apply only to structures in which each link has two joints only, and is stressed only along the line joining these two joints. A simple modification of the meaning of the formula, however, makes it applicable to structures containing beams; that is, links whose transverse sections are subjected to shear forces and bending moments. The modification is that each beam is to be counted as one link only, no matter how many joints it contains, and that in counting the joints only two occurring in any beam are to be included in the reckoning.

For stable equilibrium, the plane structure requires at least two ports, while the solid structure must rest on its foundation at three places.

In a plane structure, supported at two places, the condition of force- and moment-balance is sufficient to determine the two magnitudes of the supporting forces and the direction of one of them only; the direction of the other (or what comes to the same thing, the magnitude of the abutment thrust) being determined by conditions irrespective of the balance of the load.

In a solid structure, secured to a base at three places, the condition of force- and moment-balance of the loads is sufficient to determine six only of the elements defining the three supporting forces; for instance, the three magnitudes and the three directions in elevation. The three directions in plan must, in this case, be determined independently of the condition of equilibrium. If there be four supporting forces, from this condition the four magnitudes and two directions, either in plan or elevation, can be calculated.

In what follows, the structure is represented in plan and elevation, and the stress-diagram is also shown by help of plan and elevation. To these is added what may be called a "composition diagram," in which the components of stress, found by means of the plan and elevation, are combined into total or resultant stresses.

Bow's notation of the diagrams is used. Here, as in plane problems, the letter-names are given to surfaces or superficial polygons bounded by the links. These polygons are called "pens." Capital letters and numbers are given as names to the pens in the frame-diagram, and corresponding small letters and numbers to the corresponding points in the stress-diagrams.

In building up a stress-diagram, a certain cyclic order must be adhered to throughout the whole construction, the stress-lines being arranged in the stress-polygon for each joint in the same order as that in which the links are met in making a circuit round the joint. This may be either left-handed or right-handed cyclic order, there being two different possible stress-diagrams, which are the exact reverse of each other. In plane problems there is no difficulty in following this rule. In the solid construction, however, the pens, which may lie clear of each other in the plan, generally overlap each other in elevation; and the cyclic order in which the lines of the forces acting at a joint are cut, in making the (say) right-handed circuit of the joint in plan, is not usually the same as that in which they are cut in making the circuit of the same joint in elevation. Since the pens generally lie clearer of each other in plan than in elevation, they are here lettered in plan. The bar separating any two plan-pens, C and D is called CD, and

along this bar in elevation is written CD. The cyclic order for each polygon in the stress-diagram is obtained by reference to the plan alone, and in elevation the stresses follow each other in the same order as in the plan.

To shorten the written description of the construction of diagrams, the following system of writing out the process is employed.

To express "from the two known points d and e, draw two lines parallel to D G and E G, and mark their intersection g," the symbol "$\begin{matrix} d & \\ & > g \\ e & \end{matrix} \left\| \begin{matrix} \mathrm{DG} \\ \mathrm{EG} \end{matrix} \right.$" is used. But it is understood that the general rule is to draw dg in stress-diagram parallel to D G in frame-diagram, and $e\,g$ parallel to E G. This symbol is, therefore, contracted to "$\begin{matrix} d & \\ & > g \\ e & \end{matrix}$" simply when this general rule is to be followed. But when the rule has to be departed from; if, for instance, $d\,g$ were to be drawn parallel to Q P and $e\,g \parallel$ R T the full symbol "$\begin{matrix} d & \\ & > g \\ e & \end{matrix} \left\| \begin{matrix} \mathrm{QP} \\ \mathrm{RT} \end{matrix} \right.$" is written in.

Constructions in plan are prefixed by (π); those in elevation by (ϵ) or by (σ), which latter means "side elevation."

When a point has been found in the plan stress-diagram, the corresponding point has often to be found in elevation by projecting vertically upwards from plan to elevation, or *vice versâ*. To express "find point l in elevation by drawing from point m, already known in elevation, a line parallel to ML in elevation, and by projecting vertically upwards on to this line from the point l, already found in plan," there is employed the symbol "$m \mathrel{\underline{\uparrow}} l$." The converse process of finding l in plan, from its already found elevation, is written "$m \mathrel{\overline{\downarrow}} l$." If the line to be drawn in plan from the known point m is to be parallel, not to M L, but to N Q, the construction is written "$m \mathrel{\overline{\downarrow}} l \parallel$ N Q." This latter symbol, however, is seldom needed.

To express "find point f by plotting from h (already known), the line hf equal and parallel to $n\,o$ (also known)" there is used the symbol "$h\,f \mathbin{\#} n\,o$."

Again "$k\,l \mathbin{\#\!\!\!\equiv} s\,t$" means "plot from the known point k the line $k\,l$ equal and *opposite* to $s\,t$."

Plate 12, Fig. 1, represents the simplest possible solid structure, namely, a tetrahedron. It has four joints and six bars, and therefore fulfils the condition of stiffness and non-redundancy, $l = 3\,j - 6$, or $6 = 3 \times 4 - 6$.

The construction is shown in its most general form. By taking

special planes of projection it may be made easier, but would then illustrate the method only imperfectly.

A B C and $A^1B^1C^1$ are any two projections of the frame on two planes at right angles to each other. G G is taken as ground line. The names A B C are given to the plans of the three upper faces of the tetrahedron, and **1, 2, 3, 4,** to the plans of the outside spaces bounded by the plans of the frame and of the external-force lines. No name is given to the lower face of the tetrahedron. The plan now assigns a name to each link and external-force line. The left-handed cyclic order has been followed in this diagram. In the elevation, accented letters are used to distinguish them from the plan letters, but this distinction will be found unnecessary in subsequent examples.

It is to be noted that, in plan, the joint at which the force 12 acts lies inside the boundary of the structure. An imaginary link B_1B_2, and an imaginary joint **1** B_1B_2**2** have to be introduced in consequence, the force **12** being supposed to act at the imaginary joint **1** B_1 B_2**2.***

The data for the problem are the dimensions of the structure; the point of application, the direction and the magnitude of the load 1 2, 1′2′; the direction in both plan and elevation of the supporting force 3 4,$3^1 4^1$; and the direction of the elevation of the supporting force $2^1 3^1$.

At each soluble joint of a solid structure there act, first, a number of known forces that can be compounded into one known resultant, and, second, the three unknown stress-forces exerted by three links whose stresses have not been determined. The top joint of Fig. 1 is therefore typical of the general problem.

The mode of solution is to resolve the known force into two components, one perpendicular to the plane of any two of the unknown forces, and the other parallel to this plane. The third unknown force being imagined similarly resolved into two components perpendicular and parallel to the same plane, it is clear that its perpendicular component must be equal and opposite to the perpendicular component of the known load. If, therefore, there be plotted from the joint along the line of the known force a length representing that force to scale; and if from the end of this

* This device means nothing more than that in the stress-diagram the line representing force 12 appears twice under the two names 12 and b_1 b_2, and that the line representing the stress along bar 1 B_1 or $B_2$2, also appears twice under the two names 1 b_1 and $b_2$2. The repetition cannot be avoided when "external forces" are applied at "internal joints."

line be drawn another line parallel to one of the three "unsolved" links, to meet the plane of the other two, then the length of this line, measured to its intersection with this plane, will represent the stress along the parallel link, the scale being the same as that to which the known force has been plotted. This second force being thus found, the remaining two can be determined at once by closing the polygon by lines parallel to the links exerting them.

In Fig. 1 the force 12 is plotted to scale from the joint to the point $f f^1$ in plan and elevation, and from $f f^1$ is drawn a line parallel to A B, A^1B^1 to intersect the plane of A C, B C. The intersection is lettered $q\, q^1$, and is found as follows:—The vertical and horizontal traces of the plane A C, B C, are found in the well-known manner. They are marked in the diagram $V_{AC,\, BC}$, and $H_{AC,\, BC}$. Through f and f^1 are now drawn lines $f q$ and $f^1\, q^1$ parallel to A B and $A^1\, B^1$. These are plan and elevation of the line through $f f^1$ parallel to A B, $A^1\, B^1$. The plan $f\, q\, m\, n$ is also the plan of the line of intersection of a vertical plane through this same line and the plane A C, B C. The plan cuts $H_{AC,\, BC}$, in a point m, whose elevation is m^1 on G G. This is one point in the intersection just mentioned; it is the point where this intersecting line cuts the horizontal plane. Similarly the point where it meets the vertical plane is n on G G, whose elevation n^1 is found on $V_{AC,\, BC}$. Thus $m^1\, n^1$ is the elevation of this intersecting line. Since $q\, q^1$, the point sought, lies in this line of intersection, therefore, if $m^1\, n^1$ be produced to meet $f^1\, q^1$ in q^1, and q on $f\, q\, m$ be obtained by vertical downward projection from q^1; $q^1\, q$ is the point where the line $f^1\, q^1$, $f\, q$ through point $f^1\, f$ parallel to $A^1\, B^1$, A B meets the plane of A C, B C. Thus $q\, f$ and $q^1\, f^1$ are the plan and elevation of the stress on the bar A B, $A^1\, B^1$.

In the elevation and plan stress-diagrams are now plotted—

$$a\, b_1 \;\#\; q f \qquad a^1\, b_1{}^1 \;\#\; q^1\, f^1 \qquad b_1\, b_2 \;\#\; 12 \qquad b_1{}^1\, b_2{}^1 \;\#\; 1^1\, 2^1$$

and the points c and c^1 are obtained by drawing

$$(\pi)\ \begin{matrix} b_2 \\ a \end{matrix} > c \,\Bigg\|\, \begin{matrix} B_2\, C \\ A\, C \end{matrix} \quad \text{and} \quad (\epsilon)\ \begin{matrix} b_2{}^1 \\ a^1 \end{matrix} > c \,\Bigg\|\, \begin{matrix} B^1\, C^1 \\ A^1\, C^1 \end{matrix}.$$

The point a^1 having been chosen vertically over a, the points $b_1{}^1\, b_2{}^1\, c^1$ will be found exactly above $b_1\, b_2\, c$ if the drawing be accurate. This is a useful check. It may at once be said that it requires the most careful possible draughtsmanship to maintain

accuracy throughout a complicated solid stress-diagram; and that it is practically impossible to get it to "close," at the final polygon, unless throughout the whole construction the accuracy of the drawing be continually checked, by making sure that every point in elevation is exactly over its plan. The only satisfactory way to do this is to draw one, two, or three (according to the size of the diagram) lines across the paper very accurately vertical, and to measure horizontally with the dividers from each pair of points to one or other of these lines.

Next in plan, from joint (C **34** A) along A C to p, is plotted a length $= a\,c$. Through p so found, and its elevation p^1, is drawn a line parallel to **34**, $\mathbf{3}^1\,\mathbf{4}^1$, these directions being among the data. The intersection of this line with plane C **3**, **4** A, is next found. This involves the finding of the traces of this plane. They are ascertained as in the previous case, and are marked $V_{C3,\,4A}$, and $H_{C3,\,4A}$, and the intersection, found as before, is marked $r\,r^1$. Then $r\,p$ and $r^1\,p^1$ are the projections of the supporting force 34. From r and r^1 are drawn $r\,s \parallel$ A **4** and $r^1\,s^1 \parallel A^1\,\mathbf{4}^1$ to meet C **3** and $C^1\,\mathbf{3}^1$ in s and s^1. Then $r\,s$, $r^1\,s^1$ is the stress on **4** A, $\mathbf{4}^1\,A^1$; and the lines from $s\,s^1$ to the joint (C **3 4** A) give the stress on C **3**, $C^1\,\mathbf{3}^1$. The polygon of stress for this joint is thus completed; but as it is not in correct cyclic order, it has to be rearranged in inserting it in the stress-diagram. It there appears as $a\,c\,3\,4\,a$ and $a^1\,c^1\,3^1\,4^1\,a^1$.

Next for the joint (**2 3** C B), the two forces exerted by the bars **3** C and C B are already known, and as the directions in elevation of the two others are known ($2^1\,3^1$ in direction being among the data), the polygon can at once be completed in elevation by drawing

$$(\epsilon)\ \begin{matrix} b_2{}^1 \\ 3^1 \end{matrix} > 2^1 \left\| \begin{matrix} B^1\,\mathbf{2}^1 \\ \mathbf{3}^1\,\mathbf{2}^1 \end{matrix} \right. .$$

Then in plan 2 is found by

$$(\pi)\ b_2 \updownarrow 2.$$

Plan 2 is now joined with 3, the second supporting force 2 3, $2^1\,3^1$ having been now calculated.

Next the stress parallelograms in plan and elevation for the imaginary joint (**1 2** $B_2\,B_1$) are drawn in; thus—

$$\begin{matrix} b_1 \\ 2 \end{matrix} > 1 \left\| \begin{matrix} \mathbf{B\,1} \\ \mathbf{21} \end{matrix} \right. \quad \text{and} \quad \begin{matrix} b_1{}^1 \\ 2^1 \end{matrix} > 1^1 \left\| \begin{matrix} B^1\,\mathbf{1}^1 \\ \mathbf{2}^1\,\mathbf{1}^1 \end{matrix} \right. .$$

It only remains to join points 4 and 1, 4^1 and 1^1. These give the

remaining supporting force; and it will be seen that the diagram for the joint at which this force acts is complete.

It should be noticed that, in this example, there does not occur at the end of the construction the usual check of the accuracy of the work customary in plane diagrams. The tests mentioned above, regarding pairs of points being vertically above and below each other, are only partial, and would not reveal any miscalculation of the supporting forces due to wrong method, &c.

The absence of this check is due to the case not being perfectly general. The known load applied to the structure is here represented by a single force. In the general case the group of known forces is incapable of being reduced to a single equivalent force. It may be reduced to one force plus a force-couple; but this reduction is not a convenient one for the present purpose. Another mode of reduction is to two non-intersecting forces perpendicular to each other. For the present, as well as for other purposes, this latter reduction is more convenient because, in making it, one of the two forces may be taken in any convenient direction. The whole set of forces is reduced to one force lying in a certain plane (which may be chosen as any whatever) and a second perpendicular to this plane.

As this mode of reduction is not mentioned in books, the convenient graphic mode of effecting it is shown in Fig. 2. Here three rectangular planes of projection are represented by (π), (ϵ), and (σ), or "plan," "front," and "side elevation." The individual forces of the system to be dealt with are to be represented in projection on each of these views. Each set of projections is to be compounded into a single resultant by the ordinary well-known graphic method. These three resultants are marked ρ_π, ρ_ϵ and ρ_σ. Now the whole group of forces may be looked on as equivalent to ρ_π parallel to the horizontal plane and the vertical component (parallel to O V) of ρ_π or ρ_ϵ. Calling this vertical component ρ_v; calling the component of ρ_π or ρ_ϵ parallel to O E (say east) ρ_e; and that of ρ_π or ρ_σ, parallel to O S or O S[1] (say south) ρ_s; the system may also be resolved into ρ_ϵ along with ρ_s, or into ρ_σ along with ρ_e. To determine the relative positions in which these forces must be taken, suppose ρ_π to act (horizontally) at the level *a b*; draw *a d* $\perp$ O E, and plot on this line the point *d* at the same distance from O E that *b* stands from O V. Then the whole system is equivalent to ρ_π taken at the height *b a*, and ρ_v acting along the vertical line whose plan is *d*. The position of *d* depends on the height chosen for ρ_π. Draw $d\,d^1 \parallel \rho_\pi$; then $d\,d^1$ is the locus of the possible positions of *d*.

Similarly, if f and e are taken on ρ_π and ρ_σ at equal distances from O E and O V, and if $e g \perp$ O V and $f g \perp$ O E; then the system is also equivalent to ρ_e taken in an east-vertical plane through f or e, together with ρ_s (the southward component) taken through point g. If $g g^1 \parallel \rho_e$, then $g g^1$ is the locus of possible positions for g, corresponding with ρ_e taken at different distances south of the vertical plane O E. Again, from any point i in ρ_e are drawn $i h \perp$ O E and $i k \perp$ O V, and the point k is placed at a distance from O V equal to that of h from O E. $k k^1$ is drawn $\parallel$ to ρ_σ. Then k is the position at which ρ_e (the east component) must be taken along with ρ_σ taken in the south vertical plane through i or h, in order that these two may be a correct equivalent for the whole system of given forces. $k k^1$ is the locus of k.

Fig. 3 shows the general method of finding three unknown supporting forces of a solid structure. The points of application $\alpha \alpha^1$, $\beta \beta^1$ and $\gamma \gamma^1$ of these forces are supposed to be known both in plan and in elevation. The directions in plan **3 4**, **4 5** and **5 1** are also taken as known. The loads on the structure have been compounded in three rectangular projections to ρ_π, ρ_e and ρ_σ. On ρ_e any point δ^1 is chosen, and from it by the construction of Fig. 2 is found δ in (π), such that the whole set of loads is equivalent to ρ_π at the level of δ^1, and the vertical component of resultant load ρ_v through δ. Next draw $\delta \lambda \parallel \rho_\pi$ to meet $\alpha \gamma$ (any side of the triangle $\alpha \beta \gamma$) in λ. Project upwards from λ to λ^1 on ρ_e. The whole set of loads is now taken as equivalent to ρ_π at the height λ^1 and ρ_v at λ. Draw $\lambda^1 \theta^1$ horizontal and take on it θ^1 directly over θ, the intersection of ρ_π and $\alpha\gamma$. A linkage with the five joints $\alpha \alpha^1$, $\beta \beta^1$, $\gamma \gamma^1$, $\lambda \lambda^1$ and $\theta \theta^1$ is imagined erected on the base $\alpha \beta \gamma$, with the force ρ_v applied at the joint $\lambda \lambda^1$, and the force ρ_π applied at the joint $\theta \theta^1$. The face $\gamma \alpha \lambda \theta$ (including two triangular pens) is vertical, and is represented in plan by a single line; but to give opportunity for distinct lettering, the base link $\alpha \gamma$, and the oblique link $\lambda \gamma$ are shown in plan by curved dotted lines (drawn at random). In plan, also, the vertical force-line of ρ_v is shown by a finite dotted line from λ with an arrowhead attached, although its real projection is a point only. The links are $9 = (3 \times 5 - 6)$ in number, and are named **5** C, C B, B A, A **4**, C D, B D, A E, D E, and E (**1**, **2** or **3**). The pen D is divided in two parts by ρ_π, and E into three parts by ρ_π and ρ_v (in plan).

The horizontal components of the forces ρ_π, or **1 2**, **3 4**, **4 5** and **5 1** must balance among themselves. Therefore the lines **4 5** and **5 1** are produced to meet in ν and ρ_π, and **3 4** to meet in μ; and $\mu \nu$ is joined. Then the resultant of ρ_π and 34 must lie along the line $\mu \nu$

and that of **4 5** and **5 1** also along the same line, because these two resultants balance each other.

In the plan stress-diagram draw

$$(\pi)\ d_1\, d_2 \# \rho_\pi \qquad \substack{d_1 \\ d_2} > 4^1 \left\|\begin{matrix}\nu\,\mu \\ 3\,4\end{matrix}\right. \quad \substack{d^1 \\ 4^1} > 5^1 \left|\begin{matrix}\mathbf{1\,5} \\ \mathbf{4\,5}\end{matrix}\right.$$

Then $d_2\, 4^1$, $4^1\, 5^1$ and $5^1\, d_1$ are the plans of the three supporting forces sought, namely **3 4**, **4 5** and **5 1**.

In the rest of the construction the right-handed cyclic order has been followed.

For the balance at joint θ, since the plane D B and C D is vertical, the resultant of the two forces exerted by these bars is in plan along the line $\alpha\,\gamma$. Therefore, draw

$(\pi)\ \substack{d^1 \\ d_2} > c^1 \left\|\begin{matrix}\mathrm{D\,C} \\ \mathrm{B\,C}\end{matrix}\right.$. Then in (ϵ) draw $d_1\, d_2$ horizontal, and place $d_1\, d_2$ in (ϵ) directly over $d_1\, d_2$ in (π), so that $d_1\, d_2$ in (ϵ) represents the elevation of the known force ρ_π acting at θ^1. Then draw

$$(\epsilon)\ d_2 \uparrow c^1 \parallel \mathrm{B\,C}.$$

Thus $d_2\, c^1$ in (π) and (ϵ) represents the force exerted by link B C at joint θ. Next draw

$(\epsilon)\ \substack{d^1 \\ c^1} > c \left\|\begin{matrix}\mathrm{D\,C} \\ \mathrm{D\,B}\end{matrix}\right.$ and $c\, b \# c^1\, d_2$. This gives b in the line $d_1\, d_2$, because link D B is horizontal, and, therefore, parallel to $d_1\, d_2$. Next draw

$(\pi)\ d_2 \downarrow b \parallel$ D B and $d_1 \downarrow c \parallel$ D C. Join $b\,c$. This gives $b\,c \# d_2 c^1$ if the drawing has been accurate. The stresses in the three bars D B, B C and C D are now given in (π) and (ϵ) by $d_2\, b$, $b\, c$ and $c\, d_1$.

At joint λ the bar A B has no stress in it, because the other three forces lie all in one (vertical) plane. In both (π) and (ϵ), therefore, a is marked coincident with b, and then

$(\epsilon)\ d_2\, e_1{}^1 \# \rho_v \quad \substack{e_1{}^1 \\ a} > e_3 \left\|\begin{matrix}\mathrm{D\,E} \\ \mathrm{A\,E}\end{matrix}\right. \quad e_3\, e_2 \# \rho_v$. Join $e_2\, d_2$. This gives $d_2\, e_2 \# e_1{}^1\, e_3$.

$(\pi)\ a \downarrow e_3$, and e_2 coincides with e_3, because $e_2\, e_3$ or ρ_v is vertical. The polygon for this joint is now complete in both (ϵ) and (π), viz., $a\, b\, d_2\, e_2\, e_3\, a$. (By accident the point $(\epsilon)\ e_2$ falls on line $c\, b$.)

For joint α draw

$(\pi)\ \substack{a \\ 4^1} > 4 \left|\begin{matrix}\mathrm{A\,4} \\ \mathrm{A\,E}\end{matrix}\right. \quad 4\ 3 \# 4^1\, d_2$. This gives 3 on line $e_3\, d_2$, which line must be produced to 3. Then draw

$(\epsilon)\ e_3 \uparrow 3 \quad a \uparrow 4$. Join 3 4.

The polygon $a\,e_3\,3\,4\,a$ for this joint is now complete in both (π) and (ϵ).

For joint β draw

(π) $4\,5 \# 4^1\,5^1$. Join $c\,5$. If the drawing has been accurate $c\,5 \parallel C\,\mathbf{5}$. Draw ($\epsilon$) $c \updownarrow 5$. Join $5\,4$. The diagram $c\,b\,a\,4\,5\,c$ for this joint is now finished.

Next plot—

(π) $5\,1 \# 5^1 1^1$. Join 1 3 and mark 2 coincident with 3.

(ϵ) $3\,2 \# \rho_v$ $2 \updownarrow 1$. Join 5 1.

There are now obtained the elevations 3 4, 4 5 and 5 1 of the three supporting forces sought for, which are therefore completely known. As a check, the diagram for joint γ should be finished by drawing (π) $e_2\,e_1 \# d_2\,d_1$. Join $e_1\,1$ which should lie on line $c\,d_1$. (ϵ) $1 \updownarrow e_1$. Join $e_1\,d_1$ which should be parallel to E D. It will also be found that there are three parallelograms, showing the balance at the three imaginary joints ($\mathbf{2}\,\mathbf{3}\,E_3\,E_2$), ($\mathbf{1}\,\mathbf{2}\,E_2\,E_1$) and ($E_1\,E_2\,D_2\,D_1$).

In the "composition diagram" the external forces alone have been shown. From any point O^1 are plotted horizontally the plans of these forces, and vertically the vertical components only (not the elevations), these latter being obtained from (ϵ). Both points thus obtained for each force are marked with the proper name of the force; for example, the diagonal distance between the two points marked 4 5 gives the total magnitude of this force. The inclinations of these diagonal lines, to the horizontal line through O^1, also give the actual inclinations of the force-lines to a horizontal plane. The dotted diagonal from 1 2 to 2 3 gives the magnitude that the resultant load would have if it were capable of being looked on as a single force; it being, however, incapable of being properly so regarded.

Of course, any other imaginary link-work on the base $\alpha\,\beta\,\gamma$, and with two other joints in any of the possible lines in which ρ_π and ρ_v may be taken, would also serve to find graphically the three supporting forces; but the choice of this particular one here used saves labour, because the traces of planes have not to be found by special construction, and because $a\,b = 0$.

Fig. 4 shows a complete example of the application of these methods. The structure is a pier on a rectangular base. The dimensions are not taken from any actual pier, but have rather been chosen so as to make this illustrative example not difficult to read; that is, so as to give, as far as possible, the plan-pens clear of each other.

At the top joints four known vertical forces, A_1A_2, A_2A_3, A_3A_4,

and A_4A_1 act. At two of these top joints and four other joints at one side, transverse forces act, which may be looked on as compounded of weights and wind-pressures. These are all known, and are here taken as equal, but no use is made in the construction of their equality. The holding-down force **7 8** at one of the corners of the rectangular base is also supposed to be completely known. The plan directions of the other three foundation reactions are also among the data.

The structure is shown in plan, front and side elevation. The latter is only used for finding the unknown reactions at the base.

The known forces are plotted off in plan, front and side elevation force-diagrams in the consecutive (right-handed) order shown, giving the three unclosed polygons—

$$a_1\ a_2\ a_3\ a_4\ 1\ 2\ 3\ 4\ 5\ 6\ 7\ 8.\text{*}$$

These give three lines a_1 8, which are the vector projections ρ_π, ρ_ϵ and ρ_σ. The positions of these are found by choosing three poles, and parallel to the three pencils of lines from these, drawing three simple link-polygons, or "single-pens," through the spaces between the force-lines in the three views. Then the construction of Fig. 3 is applied to find the forces 8 9; 9,10; and 10,1 exerted by the foundation. Two of these are directed upwards; the third, 10,1, has a downward component, that is, the side forces shown will throw the holding-down bolts at this corner into tension.

The values found for these three forces are next checked by completing the three above-mentioned dotted single-pens, including the three newly-found forces. If they be found accurately, all the three single-pens will close perfectly. (In the example here shown the closure error in one of them was about 0·01 inch, and in the other two was nil, or less than the breadth of a fine line, the scale of the original drawings being 1 inch = 16 tons for the stress-diagram, and 1 inch = 5 feet for the frame diagram.)

Of the three polygons in the stress-diagram showing the balance of the external forces, the dotted one, or that in "side-elevation," is used no further.

It should be noted that in the elevations of the structure, although it is an "open" linkage, those links on the hinder surfaces are shown in dotted lines to distinguish them from those in front. Similarly in plan, two links are shown by dotted lines,

* The necessity of reducing the drawings to the admissible size of plate has led to the side elevation being shown above instead of beside the front elevation, and also to the frame and stress diagrams being placed on two separate plates. This inconvenient arrangement was unfortunately unavoidable.

namely, two horizontal diagonal bracing bars, one from joint (W X Y Q P O, &c.) to joint (L K J R S, &c.), and the other from joint (7 8 W, &c.) to joint (X 9 10 S, &c.). There are sixteen joints and forty-two links, this making the pier stiff and non-redundant.

The space A is divided into four spaces, in order that there may be names for the four vertical loads applied at its corners. In the plan stress-diagram, of course, these four forces are all represented by one point, namely, a.

A sort of gap or hiatus in the elevation diagram makes it necessary to repeat the points a_1 1 $i\,h\,p\,q\,y$. They are thus marked in the upper part, and $a^1{}_1$ 1^1 i^1 h^1 p^1 q^1 y^1 in the lower part of the elevation diagram. This hiatus is due to the external forces A_1A_2, A_2A_3, &c., having these lines shown in an internal space. It could have been avoided by drawing these four lines outward, instead of inwards. They would then cut up the other pens into a large number of subdivisions, a large number of imaginary joints and imaginary links, and stress-lines representing the stresses on these imaginary links, would need to be introduced into the construction. As the wind-force lines already cut up the pens to a considerable extent, this extra confusion is avoided by permitting this gap. From h to h^1 the vertical distance equals the sum of the four vertical loads.

The pens V N J R are each split into two by the line of the horizontal diagonal across the base. Similarly, pens O and K are split in two by the line of the horizontal diagonal at the level of Q Y and M U.

Since all except these two bars lie in one or other of four main planes, two of which are perpendicular to the elevation projection plane, the traces of planes need not be found by special construction, except in solving one joint. Thus, the resultant of the forces $q\,j$, $j\,k$, $k\,c$, $c\,b$, $b\,i$ is known to be in elevation parallel to the elevation I B or J K, independently of the individual magnitudes of these forces. This greatly lessens the labour of construction, but as nearly all engineering structures may be shown on projections suitably chosen, so as to afford similar advantages, this example is a fair illustration of the amount of labour involved in solving the stress problem by this graphic method.

The construction proceeds as follows, using the notation already explained. Note that as bars A B, C K, J R, S 10, A F, G O, N V and W 8 are perpendicular to the (ϵ) plane; therefore in (ϵ) the following pairs of points coincide:—

$$a\,b,\ c\,k,\ j\,r,\ s\,10,\ a\,f,\ g\,o,\ n\,v \text{ and } w\,8.$$

To indicate that k is to be marked coincident with c, there is written simply $c\,k = 0$.

Joint (A I B).

$$(\epsilon)\ a_4 b = 0 \quad \substack{b \\ a_1^1} > i^1 \quad a_1\, i \,\#\, a_1{}^1 i^1 \quad (\pi)\ a \mathrel{\bar{\downarrow}} i \quad \substack{a \\ i} > b.$$

Joint (A E F).

$$(\epsilon)\ a_2 f = 0 \quad f e_4{}^1 \,\#\, 4\,5 \quad \substack{e_4{}^1 \\ a_3} > e_4 \,\Big\|\, \substack{\mathrm{F\,E} \\ \mathrm{A\,E}} \quad \substack{f \\ e_4} > e_5.$$

$$(\pi)\ a \mathrel{\bar{\downarrow}} e_4 \quad e_4 e_5 \,\#\, 4\,5 \quad \substack{e_5 \\ a} > f.$$

Joint (A F G H I).

$$(\epsilon)\ \substack{f \\ i} > h \,\Big\|\, \substack{\mathrm{F\,G\ or\ G\,H} \\ \mathrm{I\,H.}}.$$ Owing to symmetry of construction $i\,h = 0$.

$$(\pi)\ i\,h = 0 \quad \substack{h \\ f} > g. \qquad (\epsilon)\ h \mathrel{\bar{\uparrow}} g.$$

Joint (A B C D E).

$$(\epsilon)\ e_4 d_3{}^1 \,\#\, 3\,4 \quad \substack{d_3{}^1 \\ b} > d_3 \,\Big\|\, \substack{\mathrm{E\,D} \\ \mathrm{B\,C\ or\ C\,D}} \quad d_3 d_4 \,\#\, 3\,4. \quad \text{Join } d_3 e_4$$

$$(\pi)\ e_4 \mathrel{\bar{\downarrow}} d_4 \quad d_4 d_3 \,\#\, 3\,4 \quad \substack{d_3 \\ b} > c. \quad (\epsilon)\ b \mathrel{\bar{\uparrow}} c.$$

Joint (H G O P). No external force acts here, and the bars O P and H G are in alignment; therefore, the stresses in these two bars are equal, since only two other forces act at this joint. $\therefore\ o\,p = g\,h$.

$$(\epsilon)\ g\,o = 0 \quad h\,p = 0. \qquad (\pi)\ g\,o = 0 \quad h\,p = 0.$$

Joint (D C K L).

$$(\epsilon)\ c\,k = 0 \quad d_3 l_2{}^1 \,\#\, 23 \quad \substack{l_2{}^1 \\ k} > l_2 \,\Big\|\, \substack{\mathrm{D\,L} \\ \mathrm{K\,L}} \quad l_2 l_3 \,\#\, 23. \quad \text{Join } l_3 d_3.$$

$$(\pi)\ d_3 \mathrel{\bar{\downarrow}} l_3 \quad l_3 l_2 \,\#\, 2\,3 \quad \substack{l_2 \\ c} > k.$$

Joint (K C B I H P Q J).

$$(\epsilon)\ \substack{k \\ p^1} > q^1 \,\Big\|\, \substack{\mathrm{K\,J\ or\ J\,Q} \\ \mathrm{P\,Q}}.$$ This gives $p^1 q^1 = 0$ and $\therefore\ p\,q = 0$.

$$(\pi)\ p\,q = 0 \quad \substack{q \\ k} > j. \qquad (\epsilon)\ k \mathrel{\bar{\uparrow}} j.$$

Joint (J Q Y R). Y R is in line with J Q. $\therefore\ q\,j = y\,r$.

$$(\epsilon)\ q^1 y^1 = 0 \quad q\,y = 0 \quad j\,r = 0. \qquad (\pi)\ q\,y = 0 \quad j\,r = 0.$$

Joint (O G F E D L M N).

(ϵ) $d_4\, d_5 \# 4\ 5$. Join $e_5\, d_5$ $\quad l_3\, l_4 \# 3\ 4$ $\quad l_4\, l_5 \# 4\ 5$. Join $d_5\, l_5$

$$l_5\, m_6{}^1 \# 5\ 6 \quad \genfrac{}{}{0pt}{}{m_6{}^1}{o} > m_6 \left\| \begin{matrix} \text{M L} \\ \text{O N or N M} \end{matrix} \right. \quad m_6\, m_5 \# 5\ 6. \text{ Join } m_5 l_5.$$

(π) $d_4\, d_5 \# 4\ 5 \quad d_5 \downarrow l_5 \quad l_5 \downarrow m_5 \quad m_5\, m_6 \# 5\ 6 \quad \genfrac{}{}{0pt}{}{m_6}{o} > n.$

(ϵ) $o \uparrow n.$

Joint (N M U V).

(ϵ) $n\, v = o \quad m_6\, u_6{}^1 \# 6\ 7 \quad \genfrac{}{}{0pt}{}{u_6{}^1}{v} > u_7 \left\| \begin{matrix} \text{M U} \\ \text{V U} \end{matrix} \right. \quad u_7 u_6 \# 6\ 7.$ Join $u_6 m_6$.

$$(\pi)\ m_6 \downarrow u_6 \quad u_6\, u_7 \# 6\ 7 \quad \genfrac{}{}{0pt}{}{u_7}{n} > v.$$

Joint (**8 9** X W).

$$(\epsilon)\ 8\ w = 0 \quad \genfrac{}{}{0pt}{}{9}{w} > x. \qquad (\pi)\ 9 \downarrow x \quad \genfrac{}{}{0pt}{}{x}{8} > w.$$

Joint (**10, 1** T S).

$$(\epsilon)\ 10\ s = 0 \quad \genfrac{}{}{0pt}{}{1}{s} > t_1. \qquad (\pi)\ 1 \downarrow t_1 \quad \genfrac{}{}{0pt}{}{t_1}{10} > s.$$

Joint (**7 8** W V U T).

At this joint the horizontal diagonal bracing bar will be called $V_1\, V_2$. At its other end it will be called $R_1\, R_2$. Its stress appears twice in the diagram as $v_1\, v_2$ and $r_1\, r_2$, the two equal and opposite pulls it exerts at the two joints. At this joint the thrust $t_7\ 7 \# t_1\ 1$ is already known. The three unknown forces are $w\, v$, $v_1\, v_2$ and $u\, t$ exerted by the bars W V, $V_1\, V_2$, and U T. Find the traces in (π) and (ϵ) of the plane containing W V and $V_1\, V_2$. They are marked long-dotted lines lettered $(\text{W V}, V_1\, V_2)^{\pi}$ and $(\text{W V}, V_1\, V_2)_{\epsilon}$. In both ($\pi$) and ($\epsilon$) stress-diagrams plot $7\ t_7 \# 1\ t_1$. Also in both (π) and (ϵ) plot from w the known stress $v_1\, u_7$ of the bar V U. Thus

$$(\pi)\ w\, v^1 \# v\, u_7. \qquad (\epsilon)\ w\, v^1 \# v\, u_7.$$

$t_7\, v^1$ in (π) and (ϵ) is the resultant of the known forces at this joint. Plot this backwards in both (π) and (ϵ) from the joint to point a.

In (π) draw $a\, \beta\, \gamma \parallel$ U T meeting $(\text{W V}, V_1\, V_2)_{\pi}$ in β, and the ground line in γ.* Project β to β^1 on the ground line, and γ to γ^1 on $(\text{W V}, V_1\, V_2)_{\epsilon}$. Draw $\gamma^1\, \beta^1$ to meet in η^1 the line $a^1\, \eta^1 \parallel$ U T in (ϵ). Project η^1 downwards to η on $a\, \beta$. Then $\eta^1\, a^1$ and $\eta\, a$ are the (ϵ) and (π) projections of the stress on U T.

* The points γ and γ^1 fall beyond the limits of the drawing as engraved.

Then proceed thus:—

$$(\pi)\ t_7\, u_7^1 \# a\, \eta \quad u_7^1\, v_2 \# w\, v^1 \quad {v_2 \atop w} > v_1 \Big\| \begin{matrix} V_1\, V_2 \\ W\, V \end{matrix}.$$

$$(\epsilon)\ t_7\, u_7^1 \# a^1\, \eta^1 \quad u_7^1\, v_2 \# w\, v^1 \quad {v_2 \atop w} > v_1 \Big\| \begin{matrix} V_1\, V_2 \\ W\, V \end{matrix}.$$

Joint (R Y X **9** **10** S).

$$(\pi)\ s\, s^1 \# v_2\, v_1 \quad s^1\, r^1 \# r\, y \quad {r^1 \atop x} > y_2 \Big\| \begin{matrix} S\, R \\ X\, Y \end{matrix} \quad y_2 r_2 \# y\, r \quad r_2 r_1 \# v_1\, v_2.$$

Join $s\, r_1$. This gives $s\, r_1 \# r^1\, y_2$.

(ϵ) $s \updownarrow r_1 \parallel S\, R$ $\quad r_1 \updownarrow r_2 \parallel R_1\, R_2 \parallel V_1\, V_2$ or $r_1\, r_2 \# v_2\, v_1$
$r_2 \updownarrow y_2$ or $r_2\, y_2 \# r\, y^1$. Join $y_2\, x$.

The stress diagram for this joint in (π) and (ϵ) is now obtained, namely, x 9 10 $s\, r_1\, r_2\, y_2\, x$. The most important check on accuracy yet obtained consists in finding the line $y_2\, x$ in (ϵ) parallel to Y X. In the drawing of this present diagram the two were exactly parallel.

Joint (V W X Y Q P O N).

Here all the forces have been found, except that exerted by the horizontal diagonal. The summation of them is not as yet, however, shown completely on the diagram. Beginning with the force $v\, w$ there is already plotted consecutively $v_1\, w\, x\, y_2$ both in (π) and in (ϵ). Next mark q_2 and p_2 coincident with y_2, because $y\, q = 0 = q\, p$. Then in both (π) and (ϵ) plot

$$p_2\, o_2 \# p\, o \quad v_1\, n_1 \# v\, n \quad n_1\, o_1 \# n\, o$$

these being mere repetitions of stresses already found. Join $o_2\, o_1$. This is the stress on the horizontal diagonal, and must be found parallel to this bar both in (π) and (ϵ). This is, therefore, a double check on the accuracy of the drawing.

Joint (K J R S T U M L).

All the stresses at this joint have now been found, although they have not been built into a consecutive diagram. This being done, there is obtained in both (π) and (ϵ) the polygon

$$k_1\, j_1\, r_1\, s\, t_1\, t_2\, u_2\, m_2\, l_2\, k_2\, k_1$$

the last stress $k_2\, k_1 \# o_2\, o_1$ being the stress on the horizontal diagonal. The double check consisting in the closure of this polygon in both (π) and (ϵ) is not independent of that given at the previous joint; it merely shows that no new errors have arisen in transferring the vectors from one to another part of the paper.

This completes the plan and elevation of the stress-diagram. From them is constructed the "composition stress-diagram," in

the manner already explained. On it can be read off to scale the whole stress on each bar of the structure along a diagonal line (not drawn), joining two similarly-named points on the vertical and horizontal axes.

No solid structure that is stiff and non-redundant, and which contains no beams, can present difficulties in the construction of its stress-diagram that are not fairly illustrated in this example; except in cases corresponding to those in plane problems where recourse has to be had to the "method of sections," or "the method of two trials and two errors." This happens when it is not possible to pass from the already "solved" part of the structure directly to a "soluble" joint. There is an example of this in the last Fig., where, having worked from the top down to joint (N M U V), it is found impossible to proceed to any joint contiguous to those already solved. There are, however, in this case two detached soluble joints, namely, (**8 9** X W) and (**10, 1** T S), which are next taken, and thus no need of the method of sections arises.

A soluble "section" in a plane structure cuts three bars. In the solid problem, the soluble section cuts six bars. The total external load on the part of the structure lying on either side of the section is reducible to two non-intersecting forces. The problem is, therefore, to find the six magnitudes of six forces whose lines of action are completely known, which will balance this known load. The analytical solution of this problem is obvious; it consists in solving six simultaneous linear equations of a somewhat complicated character. The graphic solution is not so easily recognizable. The following method, although not perfectly general, will apply to most cases likely to occur in engineering practice. It assumes that the lines of the six bars may be taken in three pairs, each of which pairs intersect in a point. Let the planes of these three pairs be called A, B, and C; and the three points in these planes, where the pairs of lines meet, be called $\alpha\ \beta\ \gamma$. Let all the external forces applied to that portion of the structure on one side of the section (not on one side of plane $\alpha\ \beta\ \gamma$) be compounded to a single force lying in the plane $\alpha\ \beta\ \gamma$, and a single force perpendicular to the same plane. Call the former force ρ_π (lying in $\alpha\ \beta\ \gamma$), and the latter ρ_v. The pair of stress-forces acting along the pair of lines meeting at α may be imagined compounded to a single force acting in plane A through point α. Refer to this still unknown resultant by the name a, and imagine it resolved at point α into two components, one a_v perpendicular to plane $\alpha\ \beta\ \gamma$, and the other a_π lying in this plane. Deal similarly with the stresses acting at β and γ, calling the components b_v and b_π at β,

and c_v and c_π at γ. By taking moments of ρ_v and a_v (whose positions are known) round the axis $\beta\,\gamma$, the value of a_v can be found; these two moments being equal and opposite, because the lines of all the other forces pass through the axis $\beta\,\gamma$. Similarly, b_v and c_v can be found by taking moments round $\alpha\,\gamma$ and $\alpha\,\beta$. After finding the positions in the diagram of ρ_v, α, β, and γ, this process can be carried out either arithmetically or by the well-known graphic construction.

Next, suppose a_π resolved into two components, both in the plane $\alpha\,\beta\,\gamma$, one being perpendicular to, while the other is parallel to, the intersection of the planes $\alpha\,\beta\,\gamma$ and A. That perpendicular to the intersecting line bears a definite proportion to a_v (namely = $a_v \times$ cot. angle between $\alpha\,\beta\,\gamma$ and A), which enables it to be readily calculated. The other acts in the plane $\alpha\,\beta\,\gamma$ along a known line, namely, the intersecting line of the two planes. Treat the forces at β and γ similarly. The problem is now reduced to finding the three magnitudes of three forces, acting along the three known lines of intersection of plane $\alpha\,\beta\,\gamma$ with planes A B C, the forces which these are to balance being now all known. This can be done by the method followed in Figs. 3 and 4. All three components of the resultant stress acting at α being now known, their resultant can be found, and this resolved into two components along the given lines of the two bars. A similar process gives the stresses along the other four bars, meeting at β and γ.

This process, as described, may appear tedious, but the work involved does not really occupy a great deal of time. After finding the points $\alpha\,\beta\,\gamma$, it will generally be convenient, for the rest of the construction, to make a plan of the six bars and the force-lines on the plane $\alpha\,\beta\,\gamma$. If it be important to find the real stresses throughout the structure, probably many engineers would prefer to carry out the "method of sections" in this graphic way, rather than by constructing and solving the six simultaneous equations that form the algebraic solution of the same problem. It must be remembered that, in order to state these equations in definite terms, it is necessary to calculate the three direction-cosines of each of the six bars, namely, eighteen direction-cosines in all.

The Paper is accompanied by two sheets of tracings, from which Plate 12 has been engraved.

(*Paper No. 2394.*)

"Tests of a Westinghouse Engine."

By Stephen Alley.

For many years the Author has given considerable attention to high-speed single-acting engines of the Westinghouse type, and has made several tests with these engines; these all go to prove that great economy can be attained in the consumption of steam if careful attention is paid to details in their design and construction. One of the most difficult sources of waste to overcome, is that due to long ports and clearances at the ends of the stroke. The great speed at which these engines run makes this detail of design the more important, as this waste is multiplied by the number of revolutions.

The advantages of high-speed engines of comparatively short strokes and high numbers of revolutions, were due to the fact that the temperature of the walls of the cylinders, in short-stroke high-speed engines, is subject to much less possibility of variation than in engines of long stroke and comparatively few revolutions. If the cylinders are properly covered with good non-conducting material the loss by radiation is very small indeed.

The accompanying Table gives a series of tests made in February 1888, at Pittsburg, U.S.A., with a Westinghouse Compound Engine

Table of Tests of a Westinghouse Engine, 14 inches and 24 inches by 14 inches Compound.

Water Rates per Brake HP. at varying Pressures and Loads.

Condensing.					Non-Condensing.				
Brake HP.	Boiler Pressure.				Brake HP.	Boiler Pressure.			
	120	100	80	60		120	100	80	60
200	19·62	22·53			200	23·94			
160	18·86	20·02	23·17		160	25·50	25·20		
130	18·38	19·56	21·32	24·30	130	24·32	26·24	27·70	
100	19·14	19·44	20·34	23·10	100	25·57	27·75	29·80	
70	19·80	20·05	21·43	22·57	90	26·51	28·30	29·80	31·70
40	22·90	23·12	24·75	25·25	70	29·40	30·77	32·48	36·00
					40	40·05	39·30	42·75	45·82

Unjacketed and uncorrected by calorimeter.

The amount of water consumed was arrived at by a surface condenser, so constructed that it condensed all the steam from the engine, and discharged it into a tank in which it was measured and weighed. Mr. Westinghouse rated the consumption of water on the brake HP., or the power developed after deducting the friction of the moving parts of the engine. While working on a condenser the consumption when using 120 lbs. of steam was on a prolonged trial 19·62 lbs. per brake HP., and when exhausting into the atmosphere, 23·9 lbs.

The Table gives the consumption of water and power developed with the engine working at pressures varying from 60 lbs. to 120 lbs. per square inch.

(*Paper No. 2300.*)

"The Monte-Video Waterworks."

By William Galwey, M.E., M. Inst. C.E.

Monte-Video, the capital of the Republic of Uruguay, has, since the year 1871, been supplied with water conveyed by pipes from the River Santa Lucia, the city having previously been dependent on "algibes" (rain-water reservoirs) attached to each house, and on a few wells. In time of drought both these sources of supply proved very insufficient, and the inhabitants were liable to considerable inconvenience and expense whenever the failure of their domestic supply obliged them to recur to other sources.

The bad construction also of many of the "algibes," and their close proximity to the "sumideros" or cesspools, from which in many instances they were only separated by a partition wall, rendered them at any time an undesirable source of supply of drinking-water, and during the prevalence of an epidemic a very real and grave danger to the public health. In addition, the water from the "algibes," even under the most favourable circumstances, is not sufficiently aerated, and is consequently but ill adapted for the use of young children or delicate persons.

It is possible to remedy this, at least to some extent, by introducing lime or charcoal, or by keeping the water in agitation as much as possible; but, as these precautions depend on individual care, they are often neglected, and the condition of "algibes" in general may be considered as unsatisfactory, at least as far as water for drinking is concerned.

The city, including the suburbs of La Aguada, Paso de Molino, and La Union, contains about ninety thousand inhabitants, occupying some sixteen thousand houses, the greater part of which are at present but one storey high. The increased value of house property and of town building lots is, however, having its effect, and many of the older houses have either had an upper storey superposed, or have been pulled down and rebuilt in such a manner as to admit of a second or even a third storey being added.

The River Santa Lucia, from which the water-supply is derived, has its sources in the mountains of Minas, composed of granite and schist rock, and on their slopes is joined by the streams of the San Francisco, Campenone, Penitentes, and Perdido, forming jointly

with them the River Alto Santa Lucia. At the Paso de Pache it receives a large tributary called the Santa Lucia Chico, and during the rest of their course the two rivers conjointly are known as the Rio Santa Lucia. The Alto Santa Lucia receives the waters of the subordinate streams Mendoza, Arias, Chamiso, Casupà, Gaetan, Soldado, Tala, and Vejigas, and the Santa Lucia Chico those of Pintado, La Cruz, Sarandi, and Tornero. The Rio Santa Lucia also receives as tributaries, before reaching the site of the pumping-station, the waters of the Arroyo de la Virgen and Canelon Grande.

The area of the entire water-basin may be calculated at 700 square leagues, and may be divided approximately as follows:—

—	Square Leagues.	Square English Miles.
Alto Santa Lucia (including Casupà, Mendoza, Soldado, and small affluents	200	1,800
Vejigas	95	855
Gaetan, Arias, and Chamiso	130	1,170
Santa Lucia Chico and branches	180	1,620
Arroyo de la Virgen	40	360
Canelon Grande	55	495
Total	700	6,300

The bed of the river is for the most part sand and gravel, with rock in the higher and more mountainous districts, and several of the tributaries, notably that of the Arroyo de la Virgen, are locally famed for the purity and coolness of their waters. Some few, as those of Tala, Vejigas, and Canelon Grande, flowing through a clay country with a slow current, carry in suspension a small portion of silica, which gives a characteristic slightly-opaline tinge to their waters.

The banks of the river and its tributaries are in general covered with "monte," or brushwood, the breadth of this belt varying from a few yards in some places to a mile in others.

The rainfall, taken at the pumping-station, has been for the last few years as follows:—

	Inches.		Inches.
1887	31·18	1884	43·53
1886	44·02	1883	57·10
1885	48·34	1882	41·65

or a yearly average of 44·47 inches.

The colour of the water is, as might be expected from the nature of the river-bed, good and bright in its normal condition, with at

times a slight opaline tinge when the river is low. In time of flood its colour is affected by clay in suspension, but the greater part of this sediment settles quickly, there being, however, a certain portion of the more finely-divided particles which it is extremely hard to get rid of.

The volume of water in the river at the point of intake has not been calculated, but towards the end of a continuous drought of three months it was considered that about 4 per cent. of the visible stream in the river was being abstracted. Under ordinary circumstances this percentage is very much reduced, and during floods the body of water is enormously increased, the river rising 15 to 16 feet, overflowing its banks, and inundating the low-lying lands on both sides over a very large area. These floods, however, seldom last long, and pumping is as much as possible avoided during their continuance, reliance being placed on reservoirs for the town supply until the water of the river is clear.

The following is the amount of impurities in 1 litre (0·22 gallon) of water taken from the River Santa Lucia, the Canelon Grande, and from the pipes in Monte-Video. These experiments were made in the year 1874:—

	Canelon Grande.	Santa Lucia.	Pipes.
	Gram.	Gram.	Gram.
Bicarbonate of lime . .	0·090	0·085	0·083
" " magnesia.	0·012	0·044	0·040
Alkaline bicarbonates .	..	0·015	0·006
" chlorides . .	0·028	0·033	0·029
" sulphates . .	0·024	0·008	0·006
Alumina and iron . .	trace	trace	0·008
Organic matter . . .	0·001	..	..

The last analysis of the water of the River Santa Lucia, made in 1888 by Mr. Henry K. Bamber, of London, is as follows:—

	Grains per Gallon.
Calcium, carbonate	3·00
" sulphate	trace
Magnesium, carbonate	1·40
Sodium, chloride	2·00
" carbonate	1·93
" nitrate	0·97
" sulphate	trace
Silica and oxide of iron	0·17
Organic and volatile matter	1·50
	10·97

	Degrees.
Hardness before boiling	1
" after "	0

Immediately below the point of intake there is a rapid in the river caused by the presence of a band of ferruginous sandstone rock, which serves as a bar to all navigation; but below this lighters and small craft laden with coal can ascend the river and discharge close to the pumping establishment of the Company.

The works of water-supply, commenced in 1868 and opened to the public in 1871, consist of a pumping station on the River Santa Lucia, a pumping main to the reservoirs at Las Piedras, the before-named reservoirs, and the gravitation main from the reservoirs to the city, including the branches and sub-branches required for the distribution of the water. The engines at the pumping-station are three in number, of 150 HP. nominal each, No. 1 working singly, and Nos. 2 and 3 being capable of either working singly or as a double engine. The pumps were originally 20 inches in diameter with 5 feet 6 inches stroke, discharging over 70 gallons for each revolution; but lately the efficiency of the single engine has been much increased by the substitution of a pump 24 inches in diameter for that originally supplied, and the result has been so satisfactory that probably some further improvements in this direction will shortly be introduced in the other engines. With the single engine, at 14 revolutions per minute, approximately 1,400,000 gallons can be pumped in twenty-four hours, and with the double engine, working at 12 revolutions, about 2,400,000 gallons in the same time.

The lift from the average level of water in the river to the engine-house floor is 23 feet, and at the above rates of speed, the pressures registered in the engine-house are 135 lbs. and 145 lbs. for the single and double engines respectively. The engines were built by Messrs. Tannet, Walker and Co., of Leeds, and, although not of a very modern design, have given satisfaction. They are exact copies of those in use by the Southwark and Vauxhall Company at Chelsea. The engine- and boiler-houses have been constructed for four engines and twelve boilers, but only three engines and seven boilers have been erected, and are found to be amply sufficient for present requirements. All the engines are provided with governors to prevent racing. The boilers are of the Cornish pattern, 29 feet 6 inches long by 6 feet in diameter, working under a pressure of 40 to 45 lbs. per square inch, and have lately been supplied with Galloway tubes, by which an appreciable saving in coal has been effected. Three boilers are used with the double engine and two with the single.

Coal is now always burned as fuel, but both coke and gas-tar have been tried, the latter with very good effect, until the increase

in its price and the uncertainty of the supply caused it to be abandoned.

The consumption of coal in the last three years, and its relation to the water pumped is shown in the following Table:—

Year.	Coal.	Water Pumped.	Lbs. of Coal to 1,000,000 gallons.
	Tons.	Gallons.	
1884	886	361,992,554	5,496
1885	987	397,720,494	5,569
1886	1,122	431,122,499	5,851

The results of 1886 must not be exactly relied upon, as experiments were conducted during that year with steam coal not at all suited to the furnaces. Having returned to Ocean Merthyr, the consumption for October, November, and December, of 1886 was respectively 5,175 lbs., 5,016 lbs., and 5,007 lbs. per 1,000,000 gallons. The amount of water pumped per month is from 45,000,000 to 40,000,000 gallons in summer and 30,000,000 to 35,000,000 gallons in winter.

The pumping main, 24 inches in diameter, extends from the pumping station on the River Santa Lucia to the reservoirs at Las Piedras, which are situated on the highest ground available, and is about 21½ miles in length. The surface of the reservoir when full is 233 feet above the floor of the engine-house. The cast-iron pipes of which the main is composed are turned and bored; they are in 12-foot lengths exclusive of socket, and 1⅛ inch in thickness at the pumping station, this, however, being afterwards reduced to 1 inch and to ⅞ inch as the pressure on the main decreases. The pipes follow pretty closely the undulations of the ground, and are provided at suitable points with automatic reflex-valves, washouts, and air-escapes. The line of pipes is daily inspected, and advice is passed to the pumping-station of any leakage that may occur, this being at once attended to by the relief gang. Burst pipes are now very uncommon, but leakage at the joints is of frequent occurrence, especially when there is much difference of temperature from one day to another or between night and day; this being due to the contraction and expansion of the metal in the pipes is to some extent unavoidable. The depth at which the pipes are laid varies from 3 or 4 feet to 10 or even more in some places, and at the crossing of streams flange-pipes are substituted for the ordinary spigot-and-faucet joints, and are cased

Fig. 1.

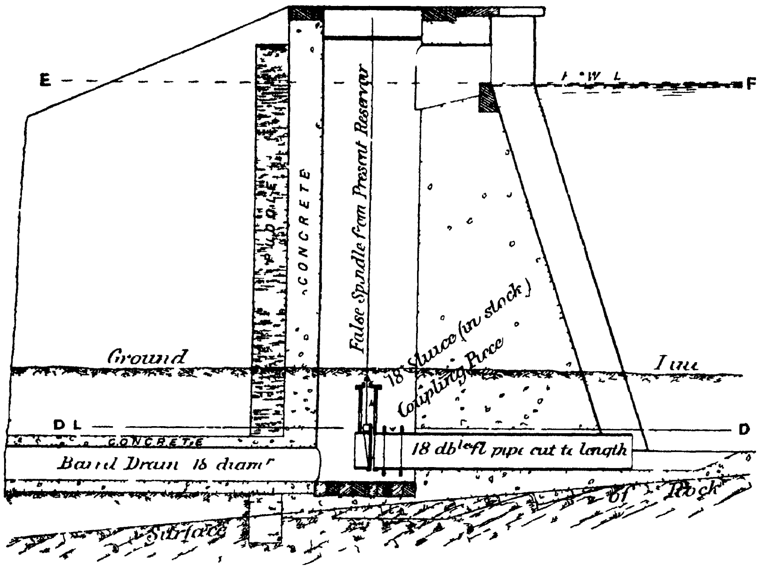
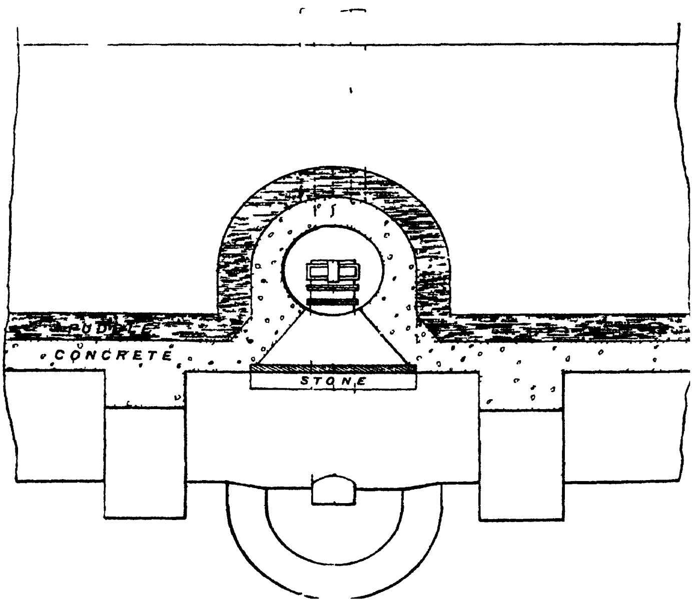


Fig. 2.

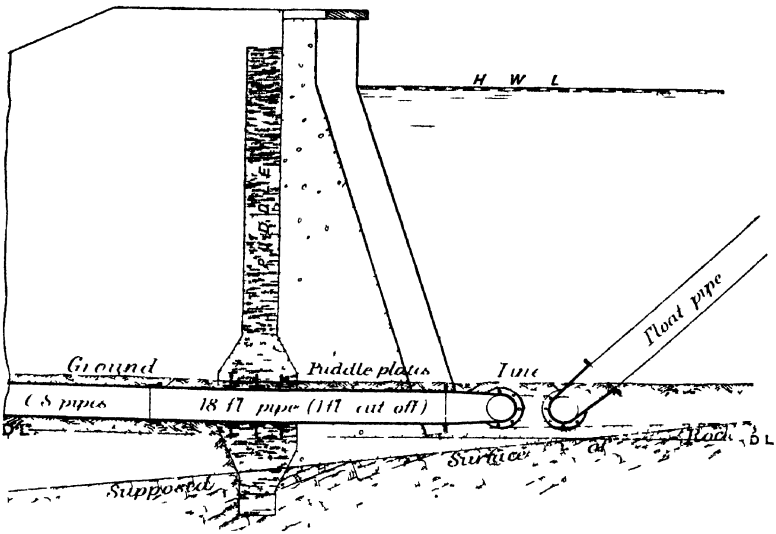


Plan at E F.

with a lagging of timber to prevent them as much as possible from atmospheric influences.

The reservoirs, situate some 12 miles from Monte-Video, on the summit level between the River Santa Lucia and the city, are two in number; and, when full, hold respectively 3,000,000 and 3,500,000 gallons of water. They are of different designs, the older one being 30 feet deep, and consisting of an earthen mound with puddle trench in centre, and stone pitching on the inside; whilst the more modern one (Figs. 1, 2 and 3) is only 13 feet 6 inches deep, exclusive of a parapet, and is formed of concrete facing, backed with puddle, and supported by a clay embankment. The

FIG. 3.



Scale $\frac{1}{100}$.

older reservoir has, on various occasions, shown signs of weakness, and has been re-backed and partially re-lined with good effect, as it is still quite serviceable. The leakage from it was at one time so great as to cause serious apprehension; but this has now been so much reduced, as to be represented by 1½ inch of water falling freely over the lip of a 6-inch pipe when the reservoir is completely full. Fig. 1 represents a section of the dam and outlet of the new reservoir, Fig. 2 a plan, and Fig. 3 a section of dam and float pipe.

The second reservoir has given no trouble since it was constructed; the maximum leakage from it has never exceeded 1 gallon per minute, and does not increase.

Both reservoirs communicate by means of float-pipes (Fig. 3), with a gauge-tank in connection with the city supply-pipe, the valves of which work automatically, and thus ensure the pipe always remaining full. The leakage of both reservoirs is also diverted into this gauge-tank, so that no loss arises from this source.

The reservoirs are provided with Bailey's water-clocks, registering the amount of water daily pumped, and, the gauge in the tank-house being similarly provided, the quantity of water supplied to the city is accurately known, as well as the loss occurring in reservoirs from leakage and evaporation. These combined losses vary from 500,000 to 750,000 gallons monthly, according to the season of the year; but it has not been found possible to ascertain the exact amounts due to each cause, the reservoirs seldom or never remaining at the same level, except for very short periods.

The water in one of the reservoirs is allowed to settle, while the other is being used, and, in case of the water in the river being cleaner and better than any of that stored, means are provided for pumping direct into the gauge-tank without having recourse to either of the reservoirs. This latter system is, however, rarely resorted to, and is not desirable, as it is impossible to regulate the pumping so as to keep the town main full without suffering a considerable loss of water, especially at night. This loss when, by the orders of the sanitary board, water was pumped direct to the city during the months of January, February, and March of 1887, amounted to 5 per cent. of all the water pumped during that period.

From the gauge-tank at the reservoirs, a 24-inch main conducts the water by gravitation to the city of Monte-Video, after some short distance narrowing to 21 inches, and almost immediately after to 18 inches, at which diameter it continues until its arrival at the outskirts of the city, dividing at the Camino Goes into two mains of 15 and 10 inches respectively; these enter the city at different points, and supply separate districts, terminating, after suffering reductions to 12, 10, 8, and 6 inches, in 5-inch washouts.

From these mains, branches are laid on about every 100 yards, and the city being built in squares, lends itself to this arrangement with considerable facility. The branches are 7 inches in diameter at their junction with the main, and are subsequently reduced to 4, 5, and 3 inches. From these other sub-branches, each 100 yards in length, diverge at right-angles at each 100 yards of distance, and are 3 inches in diameter. All branches and sub-branches are terminated by a hydrant capable of taking a 2½-inch hose, and thus

provide not only for the due cleansing of the pipes, but also as a very efficient high-pressure service in case of fire.

The maximum pressure is about 85 lbs. to the square inch at the custom-house and wharves, and from 70 to 40 lbs. in the higher parts of the town, according to their elevation. During the day, this pressure is considerably reduced by the draw-off for private services, especially in the early hours of the morning when the consumption is greatest.

The total length of branches and sub-branches, irrespective of the mains, is about 92 miles, and constant additions are being made to this length.

The house-connections are made of lead pipe, tinned inside, and are in the great majority of cases ½ inch in diameter. Each service is provided with a stop-cock placed in the street, and the taps are invariably of the screw-down pattern, as plug-taps are found insufficient to resist the pressure.

About seven thousand two hundred houses are now supplied, and this number is steadily increasing, not only by the water being laid on to newly-built houses, but also by its adoption in old houses which, until lately, were supplied by the "algibes."

In the outbreak of cholera, which took place in the summer of 1886–7, the utility of the pipe-water was very satisfactorily proved, as the epidemic was mostly confined to those districts only partially supplied or wholly unsupplied with this requisite, and was eventually driven out of these strongholds by the introduction of free drinking-posts laid in temporarily by the company for the benefit of the poorer classes.

About half the existing number of services is by meter, and the remainder by pea-ferrule at a fixed rate per month, and there is a tendency among consumers to prefer the latter method. The meters in use are of various kinds, comprising those of Tyler and Sons, Siemens and Halske, Guest and Chrimes, Kennedy, and Frost. The piston-meters of both Kennedy and Frost record more accurately than the others, but are also more expensive and cumbersome. The Frost meter has given considerable satisfaction during the time that it has been in use.

The company supplies gratuitously all public ornamental fountains and gardens, and also a certain number of free drinking-posts in situations fixed by the municipality; these are of considerable service to the more needy inhabitants.

Every week one-half of the hydrants in the city are opened for a short period until the water runs perfectly clear, and thus stagnation is avoided at the lower levels where the consumption is some-

times small. There are about six hundred hydrants, and 1,000,000 gallons of water are used in this way during the month.

In view of the large and continued increase in the number of consumers, the company has decided to lay a new 18-inch main from the reservoirs to the city, the pipes for which have been ordered in England, and some of them have already arrived and been laid.

It has also been found advisable to erect tanks for the service of the suburb of the "Union," which, standing on very high ground, has hitherto failed to obtain a constant supply during the hours of greatest consumption; and for this purpose two steel tanks, capable of holding 50,000 gallons each, have been constructed on a suitable masonry tower, which, filling automatically at night, ensures an ample day supply for the above-mentioned suburb, the water being prevented from running down to the city during the day by a reflex valve which works automatically, and requires no special supervision.

The tariff for water by meter is at present \$0·20 (10*d.*) per pipe of 100 gallons for consumers of less than two pipes per day, \$0·15 (7½*d.*) for those whose consumption is between two and four pipes, and \$0·10 (5*d.*) for those exceeding four pipes per day. For service by pea-ferrule, a rate is fixed by the company after inspection, and by agreement with the owner or occupier. For trade purposes some use is made of the pipe-water by brewers, artificial-ice makers, and soda-water manufacturers, and nearly all engines, whether locomotive or stationary, are supplied with this water for their boilers, for which it is specially suitable.

The capital of the Company, which was formed in 1879, is £400,000 in ordinary shares, and £250,000 of debenture stock.

The Paper is accompanied by lithographs, showing the plan and section of the pumping and gravitation mains, and also with a plan of the city, and details of the outlet pipes, &c., from which the Figs. in the text have been engraved.

OBITUARY.

RUDOLF JULIUS EMANUEL CLAUSIUS, Professor of Physics at the University of Bonn, who was elected an Honorary Member of the Institution on the 11th of May, 1875, died at Bonn on the 24th of August, 1888.

He was born on the 2nd of January 1822, at Cöslin, in Pomerania, and was one of the younger of a number of children, fourteen of whom reached adult age. Both parents belonged to families connected with the Church. The father, Carl Ernst Gottlieb Clausius, who, after a youth of hardship, had also attained priestly office, was in 1819 appointed, by Chief-President Sack, Government School Counsellor at Cöslin, where he gained distinction in connection with the re-construction of the disordered school system of the Province of Pomerania. Finding that the heavy duties of this office were affecting his health, he retired in 1833 to Ueckermünde in Western Pomerania as Pastor and Superintendent, where he again established a private school in which his sons commenced their education. At sixteen years of age Rudolf Clausius left his father's house to join two elder brothers in the Gymnasium at Stettin. There he spent a happy time, although the small allowance which his father, burdened with a numerous family, could make him necessitated many sacrifices. The naturally delicate physique of the boy was strengthened by regular exercises, particularly drill and swimming, and his mind was developed in every way under the care of excellent masters and by his own quiet plodding industry. His extraordinary talent for mathematics and physics exhibited itself, according to the testimony of a schoolfellow, in that he alone was able entirely to follow the lectures of the well-known Justus Günther Grassman, and could already, without assistance, pursue his studies further. But at the same time he was, as he himself would often relate, in doubt during the earlier years of his University career whether to choose those branches of science or that of secular history as his vocation in life. His certificate on leaving the Gymnasium in 1840, at the age of eighteen, describes him, both as regards character and mind, exactly as he proved to be in manhood, a remarkable instance of the perspicuity of his masters, and of the early maturity of his intellectual and moral powers. On leaving Stettin he went to the University of Berlin, where he heard, with the exception of the lectures of

the celebrated historian, Leopold Ranke, which he attended for a year and a half, only the mathematical and physical discourses of Dirksen, Ohm, Dirichlet, Steiner, Dove and Magnus. In order that he might not too long claim his father's assistance at the expense of younger members of the family, he undertook so early as the autumn of 1843 the duties of a House Master, which he fulfilled for three years and a half. In the summer of 1844 he passed the State scientific examination, obtaining thereby the right of teaching at public schools, and then worked until the year 1850 as mathematical, physical and arithmetical master at the Friedrich Werder Gymnasium at Berlin. At the same time he continued his studies in physics with Magnus, and for four years gained experience in scholastic duties at the Royal Seminary for Learned Studies under the celebrated philologist, Boeckh. In the year 1847 appeared his first literary works. After he had taken the degree of Doctor of Philosophy at Halle, on the 15th of July of the same year—his dissertation "De iis atmosphaerae particulis quibus lumen reflectitur" appeared in 1849 in German in "Poggendorff's Annalen"—Clausius was in the year 1850 appointed physical master at the Royal Artillery and Engineer School, Berlin. This post carried sufficient salary to enable him to establish himself at the University as a Privatdocent,[1] which he did on the 28th of December 1850. For five years he performed the duties of both offices, until in the summer of 1855 he obtained that post for which he had worked with ceaseless industry, and to which he was appointed through his scientific talents and long training as a practical master, viz., Professor in ordinary at the Polytechnic School of Zürich. He soon created for himself an extensive sphere of activity, which from 1857 included also the University of that city. With that devotion to duty which he showed to the end he wrote fresh lectures for almost every year, and conducted exercises and examinations in which exact written notes enabled him to form a sure judgment of the performance of each pupil. While in this way he gained the highest recognition from the Swiss authorities, he became at the same time an extraordinarily popular master through his winning personal manners, and also through the manly and determined manner in which he advocated with the authorities the rights of the students when he thought them prejudiced. His modesty, truthfulness, reliability, and willingness to render assistance, won for the foreigner—for he never acquired the rights of a Swiss citizen—universal respect and

[1] One who lectures at his own expense in the hope of gaining a professorship.

consideration. For his literary work, which there first reached a high point, honours were not wanting. More than forty learned societies elected him member, Haarlem being the first in 1857, then the Institution of Engineers and Shipbuilders in Scotland in 1859, Erlangen (Germany) in the same year, and in 1865 the Institute of France.

The year 1859 brought to Clausius that domestic happiness for which his disposition was fitted; on the 13th of November he married Adelheid Rimpau, a native of Brunswick and an orphan, who lived with her sister at Zürich. He remained at Zürich for twelve years, although Carlsruhe in 1858, Brunswick in 1862, and Vienna in 1866, sought to obtain him for their Polytechnic Schools; in 1867 he accepted a call to the University of Würzburg and returned to Germany. At Würzburg also his career was happy and successful; he was supported in every way by the Bavarian Government, and soon became completely at home in his new circle. It cost him a hard struggle to exchange this post for that of Professor at Bonn in the year 1869, but the hope of finding there a larger sphere of activity decided him.

Thus Clausius returned to his native country, Prussia. Although an advocate of the mathematical method in physics, his first care here, as in Würzburg, was to bring the physical apparatus up to date by making comprehensive additions, the means for which were provided by the Government. In the following year, however, the Franco-German war broke out, and his strong patriotism could not allow him to look quietly on. After the victory of Saarbrucken, he undertook the command of a division of the Ambulance Corps formed by the students of Bonn. The corps, and with it Clausius, remained actively engaged until after the battle of Gravelotte. At the great and decisive battles of the 16th and 18th of August he assisted in carrying the wounded from the field and in ministering to their sufferings. His services were rewarded by the Iron Cross. But unfortunately a contusion of the knee, received on the field, caused him for years much suffering and undermined his strength. By medical advice he learned to ride at fifty-six years of age, becoming a good and even a daring horseman, and deriving much benefit from this healthful exercise.

In 1875 Clausius met with a far greater misfortune in the sudden death of his wife. Six children, all of whom were young, were now left to his sole care, and with rare conscientiousness and devotion he performed his duties towards them for eleven years, only at first assisted by a governess. More than ever he devoted himself only to the narrow circle of his family, in which he sought

and found his sole recreation from work. His most pleasant holiday-trips were the summer visits of the German Association of Natural Philosophers—to Münich in 1877; Baden-Baden in 1879; Zürich in 1883; also foreign journeys on festive occasions, as those in 1879 and 1882 to London and Southampton, or, officially, as that to the International Electrical Exhibition at Paris in 1881. The more retired the life he led at home, the more was he pleased and refreshed by personal intercourse with celebrated men and, particularly, with scientific colleagues.

After his two eldest daughters had married, he found, in the year 1886, a second wife in Sophie Sack of Essen-on-the-Ruhr, a relative of that Chief-President who had, more than sixty years previously, appointed his father Government School Counsellor at Cöslin. In 1887 a son was born to him, and in all respects the close of his life was happy. Bonn had held him fast, although he had been greatly tempted in 1871 by an invitation to Strasburg, and still more so in 1883 by the offer of the Chair of Mathematical Physics at Göttingen. His duties became more numerous and complicated: in addition to lectures, numerous examinations and inquiries as to technical matters of all kinds occupied his time. He had also to take his part in the academical training of Prince Wilhelm, the present German Emperor, and was in later years much pleased by continuous proofs of the grateful remembrance of his distinguished pupil.

In the year 1887 he was appointed one of the Curators of the recently founded Physikalisch-technische Reichsanstalt at Berlin. His reputation steadily increased. The highest scientific honours were conferred upon him—the Copley Medal of the Royal Society, the Dutch Huygens Medal, the French Poncelet Prize, the Bavarian Order of Maximilian, the Prussian Order "Pour le Merite" for Science and Arts. His literary work was somewhat hindered by his having to act as Rector, and for six months as Curator, of the University in 1884 and 1885. But during the last years of his life he worked very hard. Besides the third edition of his "Mechanical Theory of Heat," he was continually occupied with electrical problems, and was often heard to declare that he had so many ideas to work up he would hardly find time for them. He looked forward with certainty to finish the third volume of his great work in the autumn of 1888, but in the spring that insidious disease, from which he was never to recover, made its appearance. He fought strenuously against the waning of his strength, but at the beginning of August he was obliged to take to his bed. His death came unexpectedly upon the scientific world,

even upon his nearest relatives, for he had called into play against the disease all the power of his will, and employed the last remnants of his strength in the devoted performance of all his duties.

In a fine notice appearing shortly after his death, Clausius was termed a prince in the realm of mathematical physics, and truly the part taken by him in the development of this science extended far beyond the ordinary limits. In view of the great number of his published writings, it is no easy matter, within the limits of this notice, to do justice to the importance of Clausius. More than one hundred separate treatises were published by him, partly in German and partly in foreign journals. The majority are contained in Poggendorff's (now Wiedemann's) "Annalen der Physik und Chemie," but nearly all have been translated into English and French, as well as his chief work "Die mechanische Warmetheorie," which was brought out in two volumes by Friedrich Vieweg and Son. Besides this Clausius wrote the book "Die Potenzialfunction und das Potenzial" (published by Joh. Ambr. Barth, at Leipzig), which in the lifetime of the author reached a fourth edition. With the third edition of "Die mechanische Wärmetheorie," commenced in 1888 (the two former editions appeared in 1867 and 1879), it was intended to publish the third volume concluding the whole work. The completion of this volume, the working out of which—as he himself remarks in the preface to the first volume—presented especial difficulties and had led him to new investigations, Clausius did not live to see. The manuscript of the third volume, of which about one-fourth is in fair copy, has been entrusted by the family to Privatdocent Dr. C. Pulfrich, the assistant of the deceased, who in conjunction with Professor Dr. Max Planck of Kiel, now in Berlin, will probably publish the work in the course of the present year. The editors have decided to issue at once, as a first instalment, the portion of the work now ready for the press.

Clausius commenced his literary career in the year 1847 with theoretical investigations on the refraction of light by the atmosphere, and on the intensity of the sunlight reflected by the atmosphere. The above-mentioned treatise of 1849 is of similar character, and much later Clausius repeatedly came back to these his first works; in 1866, for instance, in a paper on the relative intensity of direct and refracted sunlight. His view was that the bubbles of steam in the atmosphere exerted a preponderating influence over all other constituents on the reflection of light, and especially on the colour of the sky. According to this view, the blue colour of the sky is caused by reflection from these steam

bubbles and is termed a blue of the first order. With reference to the allied phenomena of the red glow at sunrise and sunset, and to the other phenomena belonging to the department of meteorological optics, the respective treatises in "Poggendorff's Annalen," and the "Uebersichtliche Darstellung, &c.," of Clausius, which is contained in Grunert's "Meteorologischer Optik," iv., 1850, may be mentioned. It should, however, be noticed that the "bubble" theory of Clausius has given rise to the liveliest discussions and even grave objections, and that opinions on the subject are not even now unanimous.

Although Clausius had already distinguished himself by the extraordinary acuteness of his logical reasoning, and by the great clearness and intelligibility of his style of writing in these optical and meteorological works, general attention was only directed to the young man of science when, in the year 1850, he came before the world with a treatise on the motive power of heat and the laws which may be deduced therefrom for the theory of heat itself. From that moment the name of Clausius is found in the closest connection with the most important advances in this science. For forty years of strenuous intellectual life he devoted himself to investigations on the subject of heat and the closely allied one of electricity, and chiefly to these labours Clausius owes his world-wide celebrity; it is universally considered his chief merit that contemporaneously with, and as one of the foremost of, a large number of eminent savants he assisted in the construction and strictly scientific proof of the so-called mechanical theory of heat.

The main pillars on which the present views on the nature of heat rest are the two so-called fundamental principles of the mechanical theory of heat, the first of which, the principle of the equivalence of heat and energy, or as Clausius calls it, of heat and work, formed the starting-point for the whole subsequent development. This principle broke with the prevailing theory, which assumed that heat was a substance, which was present in greater or less quantity in a body and thereby determined its temperature. The question first propounded by Mayer in Heilbronn, and afterwards, independently of him, discussed by Joule in Manchester with particular thoroughness, whether a universally applicable relationship existed between the heat produced by the compression of a gas by friction and other processes and the work expended, was answered in the sense that, in all cases where by the expenditure of mechanical work heat is developed, the quantity of work necessary to produce a given amount of heat remains the same and is independent of the particular nature of the process.

The substance (emission) theory can supply no explanation here, while the assumption of motion not only sufficiently explains the whole phenomenon, but also appears as a direct consequence of the universal mechanical laws. Imagination must be carried back to those times to appreciate at their true value the merits of Clausius, who, when this tremendous revolution in fundamental conceptions was accomplished, independently, and without waiting for further experiments, commenced the reconstruction of the theory of heat. The germs proved very fruitful in their mathematical development. They led Clausius in the first place to an accurate distinction between the internal and external work, of which the former, or rather, the equivalent of it, together with the heat present in the body determines the energy of the latter. The principle of the equivalence of heat and work was, however, not the only foundation on which the whole theory with all its consequences was to arise. Before this had been formulated, Sadi Carnot had developed, in the year 1824, out of the old theories certain ideas with reference to the transmission of heat from a hot to a cold body in a working machine; but it appeared as if the new principles, on which the validity of the first fundamental law rested, were directly opposed to the ideas expressed by Carnot. The credit of having first correctly recognised what was permanent in Carnot's train of thought unquestionably belongs to Clausius. On the basis of a new principle, that heat cannot of itself (or without compensation) pass from a colder to a hotter body, Clausius first formulated the so-called second principle of the mechanical theory of heat, developed by a modification out of Carnot's law, and traced it to correct principles. This principle is very often called the law of Carnot and Clausius, or also, briefly, Clausius' law, and has led to a series of the most important results, obtained by its application. Thus, for instance, the second law has been no less concerned than the first in the great transformation which the steam-engine, the most important of the thermodynamic machines, has undergone.

It is scarcely possible to give in a few words an explanation of what is understood by the second law of the mechanical theory of heat. In its briefest shape it has been stated by Clausius as the law of the Equivalence of Transformations, and therewith expressed, that in all cycles occurring in nature, in which a body undergoes a series of transformations of such a character that it eventually reverts to its original state, the algebraic sum of all the transformations must be nil. The separating action of heat, on the individual parts of a body, or its segregation, is thus considered as a

positive transformation, the conversion of heat into work as a negative transformation. From the fundamental property of heat, essential to its nature, by which it always equalizes existing differences of temperature and passes without compensation from the hotter to the cooler body, Clausius deduced the important natural law that the world is slowly but surely tending towards a certain limit, the condition of dead equilibrium, in which all causes for a further transference of heat will cease to exist. While the first law, in its widest application, states that the total quantity of energy existing in the world is as constant as the quantity of matter in the world, it contains no confirmation of the view according to which the whole condition of the universe is unalterable and in a condition of everlasting cyclic motion. "One often hears it said," remarked Clausius, in his peculiar simple and modest way, in the course of a lecture delivered at Frankfort, "everything in the world is cyclic. On the whole the condition of the world remains unchanged; the world therefore may exist for ever in the same way. The second law of the mechanical theory of heat contradicts this most decidedly," for this reason, namely, that not all the infinitely varied changes going on in the world are complete cycles, but many processes, such as transmission of heat, development of heat by friction, &c., are not reversible, so that the difference between positive and negative transformations can always only take place in one sense.

In the development of the mechanical theory of heat, the deductions derived from the application of the two main principles remained quite unaffected by the conceptions formed as to the nature of the motion which is called heat. But here again he is seen untiringly active in a sphere which he had made peculiarly his own, in conjunction with Krönig, Maxwell, and other scientific men, in the investigation of these phenomena of motion. The new theory of gases, to which the name of "Kinetic" has been given, has led to definite conceptions as to the size of the molecules and the length of the paths traversed by them.

Intimately related to Clausius' work in the field of the theory of heat are his investigations on electricity. The second volume on the mechanical theory of heat, which also bears the special title of a mechanical treatment of electricity, was termed by Clausius himself an independent treatise on electricity. With these undertakings he commenced simultaneously a new epoch of his creative activity, which was crowned by the discovery of a new electrodynamic principle. Space does not admit of any mention in detail of the manifold electrical problems which he subjected to a

searching mathematical analysis, and which, especially in latter years, occupied him much. It is interesting, however, to notice the views expressed by Clausius in his speech, when installed as Rector, in 1885, on the connection between the great forces of nature, and especially on the position of electricity or magnetism with regard to light and heat, which views were shortly afterwards more closely defined by him in an article appearing in "La Lumière Électrique." According to this, the part hitherto ascribed to the ether, that substance required by the theory of light, which is supposed to connect the coarser mass-particles of a body, must now be credited to electricity. It can no longer be doubted that electrical forces must be instrumental in the transmission of light and radiant heat. As an electro-dynamic or electro-magnetic theory of light had already been founded by Maxwell, Clausius considered that to gain a definite idea of the nature of electricity was a problem no longer far from solution. In connection with this point attention is directed to the epoch-making results published a very short time since by the physicist, Professor H. Hertz, of Karlsruhe (now of Bonn), by which the identity of light, radiant heat, and electro-dynamic undulations is made clear. The rays of electric force investigated are described as light-rays of very great wave-length, and they allow a repetition of the experiments on the reflection of light, refraction, and so on.

In his polemical writings—and he experienced as numerous attacks as any one—Clausius showed true nobility of character. The discussions of such attacks were always appended as a contribution to the mechanical theory of heat to the first and second volumes, and in this may be found a confirmation of what has been previously said of his personal characteristics. "I am accustomed," so Clausius writes in one part of these discussions, "always to express myself openly, and never think of covertly insinuating what I do not wish actually to say." He cared only to establish facts, and even the most malicious attacks of a personal character could not move him from this course; hence his simple and clear explanations have very great effect as criticisms.

In an obituary notice of Clausius, which appeared in an English journal, it was said that the students of Bonn had probably lost most by his death. It may be permitted to the writer of these lines, as a former pupil of Clausius for many years, here to recall to mind the great tact which characterized him as a school-man and a teacher, and the amiability which so quickly won the hearts of his pupils. Always simple and clear, almost self-evident to his hearers, were his demonstrations, in which he strove to place

himself on the level of his students. Only on working through his lectures at home did they become fully conscious of the ease with which the great teacher and savant handled even the most difficult problems.

It has frequently been noticed, as a peculiarity of the scientific work of Clausius, that he never published the results of experimental studies. It is true he never experimented, but his clear vision and practical understanding could not on that account overlook the importance of this branch of physical investigation. His theoretical treatises always go hand-in-hand with their practical application. When the steam-engine and electro-dynamic machines gave an impulse to his investigations, he was occupied, while still a teacher at the engineering school in Berlin, with the flight of projectiles, as is proved by a Paper of his, not yet published, written between the years 1850 and 1855. His participation in the electrical congress at Paris in the year 1881 led him to inquire into the absolute and practical system of electrical and magnetic measurements.

A theorist Clausius was, but always in touch with practice, and therein lies to a great extent the extreme importance which his work has had in the development of the physical sciences.

FREDERIC FOSTER LA TROBE-BATEMAN was born at the Polygon, Ardwick, Manchester, on the 22nd of July, 1853. He was educated partly at Wellington College, but left in consequence of his health not being good enough for the ordinary routine of a public school. He completed his studies under private tutors, and in 1871 entered the office of his father, Mr. J. F. La Trobe-Bateman, Past President Inst. C.E. In serving his pupilage he acquired a good deal of experience in Buenos Ayres and on the Manchester waterworks, carrying out part of the survey for the noted Thirlmere scheme of the latter undertaking. In January, 1880, he became a partner with his father and Mr. G. H. Hill, and during the partnership superintended the construction of large additions to the Ashton-under-Lyne and Oldham waterworks. In the autumn of 1881 he went to Canada where he remained nearly four years, returning in 1885, mainly on account of the illness of his wife, who died a year later. After that event he became himself invalided and unable to attend to business. Towards the of 1888 he left England with the intention of going to New

Zealand, hoping to benefit by the long sea voyage; but he was not destined to reach land again, dying off Hobart, Tasmania, on the 5th of February, 1889.

Mr. Foster Bateman was a man of considerable ability, and his early death cut short a career of much promise. He was elected a Member of the Institution on the 1st of March, 1881.

RICHARD GEORGE COKE,[1] the fifth son of Mr. D'Ewes Coke, was born on the 12th of January, 1813. He was educated at a private school at Gresley, and subsequently at Shrewsbury. He was trained in his profession by his uncle, John Coke, at Debdale Hall, who was then working the Pinxton Collieries. At the age of twenty-one he went out to Australia, then little else but a convict settlement, with trees growing where are now the finest streets of Sydney. He remained in the colonies some ten years, but came home on occasional visits. In Australia, Mr. Coke held positions under Government, but on returning to England on a visit about 1840, his father induced him to remain in England and take the management of the Pinxton collieries. Mr. R. G. Coke took up his residence at Langton Hall, Alfreton, and some time afterwards was entrusted by the Duke of Rutland with the management of his royalties and other colliery interests, and he was subsequently in charge of the Wingerworth collieries, removing his residence in consequence to Ankerbold. At a subsequent period Mr. Coke acted for the Duke of Devonshire in regard to his property in coal, and when Mr. Martyn Seymour was dangerously ill, Mr. Coke took temporary charge of the Staveley collieries. In 1862, Mr. Coke came to reside at Tapton Grove, and opened offices in Chesterfield, in partnership with Mr. M. H. Mills.

Mr. Coke rendered signal service at Clay Cross on the occasion of the disastrous inundation in 1860, when twenty-four lives were lost, and he showed great bravery in the rescue of the miners imprisoned in the Ingmanwell pit, Chesterfield, in 1863, leaping into the water up to his neck. At other periods of his career, Mr. Coke had control of Messrs. Seeley's pits, also of Shirland colliery, and he acted as consulting engineer on many occasions; he was likewise in great request as an arbitrator from his well-known character for scrupulous uprightness and fair dealing.

[1] This notice is abridged from one in the *Derbyshire Times* of March 2, 1889.

The Alfreton waterworks and other large undertakings of a similar nature were constructed by Mr. Coke.

Mr. Coke was a Fellow of the Geological Society, a leading member of the Chesterfield and Midland Institution of Engineers; on the Committee of the St. John's Ambulance Association, Chesterfield centre; Vice President of the School of Art; Vice President of the Chesterfield and North Derbyshire Hospital; Member of Committee of the School of Science; Trustee of the Stephenson Memorial Hall, &c.

He was elected an Associate of the Institution on the 1st of April, 1862, and on the 15th of January, 1878, was transferred to full membership. He died on the 23rd of February, 1889.

EDWARD JAMES GRICE was born at West Bromwich, on the 28th of February, 1834. He served an apprenticeship of seven years to his father, who was a member of the firm of Weston and Grice, of the Stour Valley Works in Staffordshire, thus acquiring a practical knowledge of the business, which included a rolling-mill and bolt-works, and he subsequently became manager. This business afterwards became merged in the important undertaking of the Patent Bolt and Nut Company, and in 1872 Mr. Grice took up his residence at Newport, in Monmouthshire, as Managing-Director of the well-known Cwm Bran Works of the Company. Here he almost entirely remodelled the works, designing new and improved machinery, and laying down railways and tramways in and about the shops, including a full-guage railway to the adjoining collieries. He also in 1875, acting under the advice of Mr. R. C. May, constructed a tunnel 1½ mile long, to win coal previously inaccessible. Mr. Grice was one of the Board of Examiners for the South Wales district, under the Mines Regulation Act; and was likewise Director and Chairman of several important undertakings in the neighbourhood, such as the Newport Slipway and Drydock Company, the Patent Enamel Company, &c.

In 1881 Mr. Grice entered the Town Council of the borough, and in 1885 was unanimously elected Mayor, his year of office being one of the most successful on record. Indeed, speaking generally, there was no more popular man in Newport than Mr. Grice. As well as being on the borough bench, he was a Magistrate for the county of Monmouth, and in the same year as his Mayoralty he was made

High Sheriff and Deputy-Lieutenant. During his year of office as Sheriff he had to devise the requisite organization for two general elections. In politics Mr. Grice was a strong Conservative, and was Chairman of the Conservative Association for the Newport boroughs. In 1885 his shrievalty was commemorated by a banquet, at which he was presented with a massive service of plate, to which was added a gold necklet for Mrs. Grice. The heavy public work of the two years 1885–6 told sensibly on Mr. Grice's health, and it became necessary that he should take a protracted rest; for this purpose he acquired a lease of Beechwood, Reigate. Here he sought rest and relaxation in improving the house and ground, and was so occupied, when, in the spring of 1889, he contracted inflammation of the lungs, from which he died on the 9th of March of the same year.

Mr. Grice was elected a Member of the Institution on the 1st of March, 1881.

EDWARD ALEXANDER JEFFREYS was born in Shrewsbury, on the 20th August, 1824; he was the son of Mr. William Jeffreys, solicitor, a member of a well-known firm in that town. At the early age of fourteen he was sent as apprentice to the late firm of Bury, Curtis and Kennedy, of Liverpool, where all descriptions of railway and marine engines and plant were manufactured. He there proved himself an energetic pupil, being principally employed in making the plans of locomotive and marine engines, and afterwards in superintending the working of them. In 1845 he obtained the appointment of Locomotive-Superintendent on the Shrewsbury and Chester Railway, being employed for the first fourteen months in superintending the construction of the rolling-stock. This appointment he held for eight years, until the railway was absorbed by the Great Western. In 1853 the late Mr. Thomas Brassey secured his services to go out to Canada as Locomotive-Superintendent of the Grand Trunk Railway, and to take charge of the construction of the rolling-stock before going out, but upon the opening of the Shrewsbury and Hereford Railway, Mr. Brassey appointed him to manage and work that line for him, as Resident Engineer and Locomotive-Superintendent during his lease; this he did until its termination in 1862. In 1863 Mr. Jeffreys became General Manager of the South Eastern of Portugal Railway, but after a few months resigned this appoint-

ment on being offered the position of Consulting Engineer and representative to the Low Moor Iron Works, which position he filled until July, 1879, when he became the partner of Sir James Kitson, Bart. (then Mr. Kitson), in the Monkbridge Iron Works, Leeds. On the conversion of the business into a limited liability company Mr. Jeffreys became a Director, and held that position until he died.

He had a very extensive acquaintance with railways and railway matters, and was regarded as an authority concerning that branch of engineering. He became a Member of the Institution on the 1st of December, 1863.

Mr. Jeffreys died, after a short illness, at his residence, Hawkhills, Chapel-Allerton, Leeds, on the 3rd of April, 1889, at the age of sixty-four.

VICTORINO AURELIO LASTARRIA was born at Santiago, the capital of the Republic of Chili, on the 22nd of November, 1843. After remaining for two years at the University of Santiago, he came to Europe towards the end of 1862, and entered the University of Ghent, Belgium, where he remained until he received its diploma of Civil Engineer in 1867, after which he returned to Chili, and was appointed an assistant engineer on the Southern Railway, and soon afterwards on some public works in the Port of Valparaiso. At this time, Mr. Henry Meiggs, the wealthy American railway contractor, was engaged in the construction of numerous railroads in Peru; he sent for Lastarria to assist in the surveys of an important line from Lima to the summit of the Andes at Oroya, and subsequently appointed him engineer for the construction of the section from Lima to San Pedro.

Hard work, and the severity of the climate, obliged him to return to Chili in 1870, on sick leave; but his health being soon restored, he occupied himself in laying out the lines of tramway for the city of Santiago, and then returned in the following year to his work on the Oroya railway, upon which he was engaged, until the end of 1872. During the three following years, the important reservoirs and irrigation works on the River Rimac were placed under his charge, and the skill with which he executed this difficult work established his reputation as an excellent engineer. He remained for two years longer in Peru, in the employment of the Peruvian Government, and then, in 1877, returned to his own country.

The Chilian Government at once secured his services, and he was employed as engineer of the section from Maule to Curicó, on the southern trunk line of Chili, which involved the construction

of bridges over the rivers Maule, Lontué and Claro. He also prepared the plans of the railway from Taltal to Refresco, which is now to be extended to Cachinal, and acted as commissioner for the Government to determine questions relating to the docks and quays of Talcahuano.

When the war broke out between Chili on the one hand and Peru and Bolivia on the other, he accompanied the Minister of War as consulting engineer, and after the conquest of the Province of Tarapacá, from Peru, in 1879, was left in charge of the railways which connect the nitrate of soda lands of Tarapacá with the seaports of Iquique and Pisagua, at that time very recently constructed, under the direction, as Chief Engineer, of Mr. H. F. Ross. For a short time he held the post of Civil Governor of that province, and after remaining there until 1881, conducted the surveys of a railway from thence across the Andes, into the Republic of Bolivia, a service of some danger, for the two Republics were still at war.

In 1882, he was appointed by the Government to survey a railroad from Santiago to Quilpué (near Valparaiso), passing through Melipilla, and in 1883, to survey a parallel line to this from Santiago to Valparaiso, *viâ* Placilla and Playa Ancha.

After this he was desired by the Government to report on the railway extensions in southern Chili, from Renaico to Victoria, and from Angol to Traigeen, of which he was named the chief engineer, and on the failure of the contractors to complete the works, was ordered to take the construction into his own hands, and finish the railways at the cost of the Government. This was a highly responsible and laborious undertaking, involving, amongst other heavy works, in the spurs of the Andes, the construction of a colossal viaduct and bridge over the Malleco, which is 422 yards in length, and crosses the river at a height of 316 feet above the water-level. He completed the whole to the entire satisfaction of the Government.

The metal work of this bridge was supplied from the Creusot ironworks, and the representatives of that powerful French establishment were so impressed by Lastarria's skill and integrity, that they authorized him to submit a tender on his own behalf to the Government for the construction of the remainder of the railway beyond Victoria, to the Port of Valdivia, and as far as Osorno, 550 miles south of Santiago, and near to the frontier of Patagonia. They guaranteed to provide him with all the capital he might require for the work, but before this important negotiation could be completed, his health failed him, and at the early age of forty-

four, Victorino Lastarria sank under the excitement and stress of his laborious exertions, and died at Santiago on the 27th of July, 1888.

The society for the Promotion of Industry (of Santiago) deputed their president to speak his funeral oration, and in so doing he expressed himself in terms of high commendation, eulogizing Lastarria's great attainments as an engineer, as well as his indomitable energy and perseverance, his sterling honesty, and other qualities befitting a citizen of honour and repute, lamenting his death as that of one whom his country could ill afford to lose.

Mr. Lastarria was elected a Member of the Institution of Civil Engineers on the 3rd of February, 1885.

DANIEL MILLER[1] was born in January, 1826, in Glasgow, where his father carried on the business of a brass-founder and coppersmith at the Saracen Foundry. Mr. Miller received his professional education in Glasgow, and he and Mr. R. Bruce Bell,[2] a companion in one of the offices in which he worked, commenced business in 1850. Success soon attended the efforts of the two friends, who were well trained by their tutors, amongst whom was Mr. Lewis Gordon, the original occupant of the chair of civil engineering in Glasgow University.

Early in his career the subject of this notice applied himself to the study of hydraulics, and in 1849 patented a hydraulic purchase machinery extensively used in docks and slips at home and abroad. Indeed, his first work of any note was the making of a slip at Kelvinhaugh. At this time there was no graving dock in Glasgow, the nearest being at Dumbarton, 15 miles distant, and Messrs. Tod and Macgregor, the eminent engine-builders and shipbuilders, got Messrs. Miller and Bell to construct a dock at their yard at Meadowside, Partick. It is 500 feet long, 56 feet broad at the entrance, and 18 feet deep on the sill at high-water spring-tides. It is still extant, and the yard is now occupied by Messrs. D. and W. Henderson and Co. In the same establishment they made a slip of 850 feet length for vessels of 2,000 tons register. Similar slips were made in various parts of the world—at Williamson (Melbourne), Cronstadt, Riga, and Alexandria. These undertakings, however, were but the preliminaries which led to more important works.

[1] The substance of this memoir is from "Engineering," Oct. 12th, 1888.
[2] Minutes of Proceedings Inst. C.E., vol. lxxv. p. 293.

The members of the firm were the engineers for the Albert Harbour, at Greenock, where Mr. Miller introduced the new system of constructing sea-walls and quays in deep water without the aid of cofferdams. Prior to this there were three open tidal docks or harbours in Greenock, and the new dock was situated in the west end. It projected almost entirely beyond the high-water line, so that valuable ground might not be used. The work was done by forming the walls under low-water of a combination of cast-iron guide piles, H section, with a continuous stone facing slid down over and inclosing these, a backing of concrete being deposited in a soft state. The entire mass, piles and stone facing, concrete backing and hearting, is allowed to consolidate, after which the heads of the iron piles and the granite facing-blocks are capped at the level of low-water by a granite blocking or string course, and the upper portion of the walls is carried up in freestone, ashlar, and rubble. A description of this work was presented to the Institution by Mr. Miller, and is printed in the Minutes of Proceedings, vol. xxii. p. 417. The firm also built Prince's Pier west of the Albert Dock, intended for the accommodation of the river steamers. Extensive harbour works were carried out at Port-Glasgow by the firm.

In the city of Glasgow Mr. Miller designed and superintended many engineering undertakings, the principal of which were the Albert Bridge and a graving dock. The dock is 560 feet long on the floor, 72 feet broad at the entrance, with $22\frac{3}{4}$ feet and $20\frac{3}{4}$ feet depths of water at spring and neap-tides respectively. The machinery, &c., was so arranged and situated that it could be utilized in pumping the water out of any new dock constructed alongside. Since that time a second dock has been made. It is 25 feet longer.

Mr. Miller had been in failing health for a considerable time before his death, but it was only a short time previously that he was entirely prevented from attending to business. He died on the 28th of September, 1888. He was elected a Member of the Institution on the 5th of April, 1864.

JAMES MUIR was born at Glasgow, on the 31st of May, 1817, his father being the Rev. William Muir, D.D., LL.D., a minister of the Established Church of Scotland, afterwards of St. Stephen's, Edinburgh, and one of Her Majesty's chaplains in Scotland. Mr. Muir was educated at Edinburgh, where he attended first the High School, and then the Academy, completing his education at

the University. Whilst awaiting an opening that would form an introduction to civil engineering, he assisted Mr. John Scott Russell, under whom he had formerly studied, in investigating the laws that govern wave-motion and that affect the movement of floating bodies through water. At the age of eighteen he came to London, and was articled to the Messrs. J. and G. Rennie, of Blackfriars. There Mr. Muir was employed in the office and workshops until the year 1841, when he entered the service of the New River Company, London, as assistant to Mr. W. C. Mylne, F.R.S. Whilst so engaged he designed a water-meter which was found to be a great improvement upon the then existing apparatus, and he was thereupon highly commended by the Directors of the Company for his ingenuity.

On the resignation of Mr. Mylne in 1859, Mr. Muir was appointed Engineer to the Company. From this time until his retirement he was energetically occupied in extending the sources of the supply, in improving the means available for its distribution, and in maintaining its quality at the highest standard of purity attainable; or, in other words, in anticipating the continually increasing wants of the large district of London of which he had charge. In order to meet the heavy demands that arose from extension of building, and the increased use of water for sanitary purposes, he sunk numerous deep wells into the chalk between Hertford and London. At most of these stations he successfully adopted pumps of comparatively small diameter and short stroke, working at a high velocity, rather than the older type of slow-moving pumps of larger calibre which had previously been used for long lifts of this kind. By deep boring at two of the wells, viz., those at Ware and at Turnford, he solved the question, so far as the country northward of London is concerned, of the possibility of finding a new source of water for the supply of the Metropolis in the Lower Greensand, a question that was formerly much discussed by geologists. At both of the places named, the stratum sought was found to exist, but in a very attenuated form and quite devoid of water.

A matter that frequently engaged his attention was the enlargement of the channel of the New River along which the supply is conveyed to town. This artificial watercourse having been formed more than two hundred and seventy years since, has from time to time needed much alteration to fit it for present requirements. In pursuit of this object, Mr. Muir renewed the aqueduct at places where diversion of the stream was required; added auxiliary conduits where the sectional area was restricted, and by various ingenious methods largely increased the carrying-capacity of the

channel. The rapid growth of the northern suburbs of London early necessitated the construction of an enlarged filtering- and pumping-station at Hornsey, where, under his direction, provision was made for lifting large quantities of water to reservoirs on the tops of the ridges extending from Hornsey to Hampstead. Long lines of large pumping-main were laid in connection with this station, as also for the service of other reservoirs built in outlying places. Among the number of these newly-made reservoirs, a pair at Crouch Hill, having a total capacity of 12,000,000 gallons, were constructed in the face of considerable engineering difficulties arising from the treacherous nature of the sub-soil.

Shortly after his appointment as Engineer to the Company, Mr. Muir re-arranged the whole system of distributing-mains throughout the town districts, forming zones of supply at the various levels corresponding to the several reservoirs. This involved the laying of a great number of pipes, varying in size up to 36 inches in diameter, and the arrangement of many new connections, the work being often carried on under great disadvantages owing to the crowded state of underground London, and the many interests, municipal and other, that must necessarily be consulted.

In 1872, when the Regulations for prevention of waste of water were framed by the Board of Trade, as prescribed by the Metropolis Water Act of the preceding year, he took an active part in collecting materials that would be of service in their compilation, his aim being to obtain for London the advantages that are possessed by most of the larger municipal Corporations, in the way of ability to prevent waste of water without restricting its use for domestic purposes. With this end in view, he also took great interest in all newly-invented water-fittings, whether for domestic or public use. Among the many details appertaining to the various structures and appliances used in waterworks, which had his studious and indefatigable attention, may be mentioned the arrangement of the filtering medium in filter-beds. He first introduced the method, which has now become general, of forming small drain-channels of common bricks laid dry in rows at the bottom of the bed, with a closely-paved covering of the same above, upon which shingle for supporting the sand rests.

In the course of the many inquiries concerning such matters as Water-Supply, Pollution of Rivers, &c., that have, from time to time, been conducted by Royal Commissions and Parliamentary Committees, Mr. Muir was often called upon to appear as a witness, in which capacity he greatly excelled, impressing all who heard

him by the readiness of his replies, and by the full and lucid, but at the same time concise, manner in which he answered questions, whether from friendly or opposing counsel. Another direction in which he showed talent to a remarkable degree was in dealing with financial affairs, for which he evinced a special aptitude. Thus it frequently happened that he was able to effect considerable economies without in any way lessening the value of the final results.

In the year 1882, having fallen into ill-health, Mr. Muir was relieved from active duty, and accepted the post of Consulting Engineer to the Company. In the succeeding year he was elected a Director, and, notwithstanding that he then resided at Bournemouth, was unremitting in his attendance at the weekly Board Meetings until about Midsummer of the year 1888, when he was seized with the illness which, after a long and painful course, terminated in his death on the 4th of January, 1889.

Mr. Muir was most conscientious and scrupulous in all his dealings, and earnestly strove to imbue his subordinates with his own intense devotion to duty. He combined a kindly and gentle disposition, with great firmness and love of discipline. His judgment was much esteemed by those who were professionally associated with him, whilst his courteous manner and readiness to assist with judicious counsel made him respected and trusted by all who knew him. In private life he was always deeply interested in works of benevolence, to some of which he unobtrusively devoted himself, especially bestowing much time to the instruction and improvement of the young.

Mr. Muir was elected a Member of the Institution on the 1st of May, 1866.

FREDERIC MURTON was born at Chatham, on the 24th of March, 1817; his father was Colonel Murton, who for some time was Commandant of the Royal Marines in that garrison. Colonel Murton was enabled from his position to make several friends; amongst others was Colonel Landmann, of the Royal Engineers, who had recently retired, and was one amongst the engineers then rapidly rising into notice owing to the development of railways. Mr. Murton was educated first at a private school at Chatham, and afterwards at the grammar school at Rochester. In the year 1834 he was articled to Colonel Landmann, who was then constructing the London and Greenwich Railway, the first

railway built wholly upon a viaduct, the Preston and Wyre Railway, and other works. After being employed in the office for the first three years of his pupilage, where he became a good draughtsman, he was placed by Colonel Landmann on the works of the Preston and Wyre Railway, under the Resident Engineer, the late Mr. Julien. Upon a change being made in the engineers of this railway, by which George Stephenson became Engineer, he was employed by that gentleman for a short time; he occupied a portion of his time in practising surveying and levelling under General Pasley, who became Inspector-General of Railways. In 1840 Mr. Murton again entered the service of Colonel Landmann, and was employed in preparing the plans for the widening of the London and Greenwich Railway, and in superintending the execution of the works, under the direction of the late Mr. John Pinhorn, the Resident Engineer, for the accommodation of the traffic of the Brighton line. Upon leaving Colonel Landmann, in the year 1842, Mr. Murton was frequently employed upon the Parliamentary surveys of projected railways. He remained thus occupied until he became engaged by Mr. Joseph Locke, Past-President Inst. C.E., and Mr. Neumann, as Resident Engineer upon the Paris and Rouen, the Rouen and Havre, and the Dieppe Railways, where he made friendships which only terminated with life. Among these friends, who afterwards became distinguished in their profession, were Mr. Locke, Mr. Meek, Engineer to the Lancashire and Yorkshire Railway, and Mr. Buddicom. He was also fortunate enough, whilst engaged on the Rouen Railway, to form a lasting friendship with the late Mr. Brassey, whom he advised upon many of his most important contracts. It was owing in a great measure to Mr. Murton's advice, that Mr. Brassey with his partners undertook to complete the Paris, Lyons, and Mediterranean line, which went only from Paris to Lyons, and from Avignon to Marseilles. Mr. Murton was employed to represent Mr. Brassey on the portion from Lyons to Avignon, and gave such satisfaction that, upon its completion, he was presented by his employers with the sum of £5,000. Upon the completion of this railway he was engaged by Messrs. Peto, Betts and Brassey, as joint manager, with the late Mr. George Giles, upon some large works in connection with the Lyons and Avignon Railway, Mr. Murton representing Mr. Brassey. Upon the completion of these works, Mr. Murton resided for several years in Paris, and was much occupied in examining railway and other projects in the interest of Mr. Brassey. On his return to England, he was engaged by Mr. Brassey to examine a project for

a railway in Norway, from a port on the Gulf of Finland to the iron-mines of Gellivara; also in the carrying out of a railway contract from Gladbach to Venlo; upon the completion of this work, Mr. Murton went, for Messrs. Waring Brothers, to Hungary and Portugal, and for other parties to North America, to examine various railway projects, and to conduct negotiations in connection therewith.

Mr. Murton, for the last few years of his life, had not been actively engaged, beyond being Chairman, from 1875 to 1887, of the Chemin-de-fer du Vieux Port et de la Banlieu Sud in Marseilles.

He died on the 17th of January, 1889, in the seventy-second year of his age, at his residence in the Addison Road, Kensington, and was interred at Brompton Cemetery.

Mr. Murton was an engineer of considerable experience and ability; painstaking in what he undertook, and in every respect reliable; a thoroughly high-principled gentleman, a good son, and kind to his relatives; he was, moreover, a staunch comrade, devoted to his profession, in which he made many close friends.

Mr. Murton was elected a Member of the Institution on the 1st of March, 1864.

WILLIAM PARKES was born near Gloucester on the 6th of October, 1822. He was educated at Bristol College and at University College, London, and being at that time of a delicate constitution, the doctors advised him to adopt a profession which would give him as much outdoor life as possible. With this view he entered the office of Mr. Hemming, an engineer in Bristol, in 1838, and after being there for a certain time, he obtained employment under the contractor who was then constructing the Great Western Railway.

In 1845 he entered the office of the late Mr. James Walker, Past-President, Inst. C. E., and while with him assisted in the preparation of the surveys and plans for various large works.

In 1847 he was sent to Alderney by Mr. Walker to report on the proposed harbour there, and, on the commencement of the works shortly afterwards, he acted as Resident Engineer under Mr. Walker, holding the position for two years.

In 1849 Mr. Parkes returned to London, and early in 1850 he started an office of his own in Parliament Street. He still retained his connection with Mr. Walker, who employed him to make

reports and surveys for the River Dee Improvement scheme and other works of a similar nature in England, besides which he made surveys for various railways which were then in contemplation.

In 1853 he was asked by Mr. (now Sir Charles Hutton) Gregory to go to Italy to superintend the work of draining Lake Fucino, but after spending a considerable amount of time and trouble the work was taken out of the hands of the English Engineers, and Mr. Parkes returned to England. About this time Mr. Walker having been requested to report on the proposal to construct a harbour at Kurrachee, Mr. Parkes was deputed to go to India to make surveys and gather materials for the report, and on his return he prepared the plans for the breakwater in conjunction with Mr. Walker, but no work was started at Kurrachee for some years afterwards. In 1860 Mr. Parkes was employed in the designing and erection of several lighthouses in the Red Sea and the Cerigo lighthouse in the Mediterranean. In 1864 he presented to the Institution a description of this work, for which he was awarded a Telford premium.[1] He also superintended the construction in England of the lighthouse which was erected on the Island of Sombrero in the West Indies.

In 1868 he went out to Kurrachee, and the construction of the breakwater was commenced, Mr. W. H. Price being left in charge of the work as Resident Engineer, and Mr. Parkes returning to England with the appointment of Consulting Engineer. This breakwater, which was completed in 1873, was the first instance of the now well-known "sloping-block" system being carried out on a large scale.

In 1873 Mr. Parkes was instructed to go to Madras to report as to the formation of a harbour at that place, and in 1875 he submitted to the Government his proposed design, consisting of two parallel breakwaters running out from the shore and turned round at the ends. This was accepted, and work was started there in 1876, Mr. Parkes going out to Madras to organize the staff and set the works going.

The harbour was on the point of completion in 1882, when a cyclone visited Madras, which had the effect of destroying the outer arms of the breakwater, and a Committee of leading Engineers was appointed in London to consider the best way of restoring the works, and on their recommendations the ruined portions of the breakwaters were ordered to be reconstructed on a strengthened design, which work is still in progress.

[1] Minutes of Proceedings Inst. C.E., vol. xxiii. p. 1.

At the time of his death Mr. Parkes was still acting as Consulting Engineer to the Madras Harbour Works, and was also the Engineering agent for the supply of wharf materials, dredging plant, &c., to the Kurrachee Port Trust for the inner improvement of the harbour.

He was elected an Associate of the Institution on the 3rd of February, 1846, and was transferred to the class of Members on the 17th of April, 1860. His sudden death from heart disease at his house at Surbiton caused the greatest sorrow, not only to his immediate relatives, but to a large circle of friends both in London and at Surbiton, where for many years he had taken a prominent part in the *management of local affairs.*

GEORGE HENRY PHIPPS, until within a very few years of his death one of the best known figures at the Institution, passed quietly away on the 11th December, 1888, at the ripe age of eighty-one. To the last he took the keenest interest in all that appertained to the profession of engineering, in which he was destined to see the rise and fruition of three distinct epochs. He began life at a period when the traditions of the older engineers of the Smeaton type still held full sway. His own active career was fulfilled in the middle period, which commenced with George Stephenson's first railway works, and ended with the death of Robert Stephenson—the eventful era of the English railway system. He yet lived to see, as an interested spectator, the full development of the third or modern period, when engineering has broken the bounds first imposed upon it as a craft restricted to the provision of means of communication, and has become one of the most diversified and wide-reaching of human vocations.

Mr. Phipps was born on the 27th of March, 1807. On completing his schooling, he was apprenticed to a firm of mechanical engineers in London. About the year 1828, he entered the locomotive works of Messrs. Robert Stephenson and Co., at Newcastle-on-Tyne, at that time busily engaged on the preliminary design of the famous "Rocket," which won the first prize at the Rainhill trials in October, 1829, and virtually decided the future of the locomotive-engine. The original rough sketch of the "Rocket" was chalked out on the floor of the drawing-office, at Newcastle, by Robert Stephenson and Mr. Phipps, and the latter took no inconsiderable part in the subsequent triumphs and disappointments that attended its realization before success was finally attained.

The Stephensons, father and son, but especially the latter, appear to have possessed a magnetic power of attracting to them, and retaining through life, the affectionate devotion of those whom they once employed; it is not therefore surprising to find Mr. Phipps' career intimately connected with that of Robert Stephenson. When the Act for the London and Birmingham Railway was obtained, Phipps followed his chief to London to assist in starting the works. "The great drawing-office at the Eyre Arms tavern, St. John's Wood, which was the headquarters of the railway company, has become classic in the history of modern engineering; for within its bare walls was located a staff of clever engineers, such as was probably never before, nor has been since, assembled at one time."[1] Mr. Phipps was one of them. His special branch was the designing of bridges, and working out of calculations, for which his mathematical powers peculiarly fitted him. When all was ready for beginning the construction, he requested that a district might be assigned to him where there was heavy work. In accordance with this desire, Robert Stephenson posted him to the Roade and Kilsby section, including the Blisworth cutting, Stow Hill tunnel, Weedon viaduct, and the heavy work through the Government ground at Weedon, but not the Kilsby tunnel. On the opening of the London and Birmingham Railway, and the consequent dispersal of the construction staff, Mr. Phipps was for two years an assistant of Mr. Brunel. He then became manager of the factory of Messrs. Alexander, Gordon, and Co., who executed a large amount of ironwork for lighthouses and beacons for the Trinity Corporation, of Deptford-le-Strond. Notable among these works were the cast-iron columns and wrought-iron bracing of the Maplin Sands lighthouse, on the estuary of the Thames. This lighthouse was remarkable as constituting the first successful application of Mitchell's screw-piles to submarine foundations. The firm also executed, during Mr. Phipps' managership, the cast-iron work for the celebrated Wolf Rock beacon, which preceded the existing granite lighthouse. On the closing of the Deptford foundry, Mr. Phipps again became associated with Mr. Stephenson, and for him made, in conjunction with Mr. George Berkley, a series of experiments and examinations of the deep wells of Liverpool, in reference to the water-supply of that city. Mr. Phipps was next engaged in conjunction with Mr. M. A. Borthwick, who was acting for Mr. Stephenson on works in Egypt, besides being himself concerned in numerous railway

[1] Minutes of Proceedings, Inst. C.E., vol. lvii. p. 297.

projects at home, at the busy time of the railway mania, when Mr. Borthwick had in one session, 1844–45, as many as twenty-two sets of plans and sections deposited. In 1852 Mr. Phipps became Engineer-in-Chief of the Western Railway of Switzerland, a line from Morges to Lausanne, and thence to Yverdun, his friend Mr. J. M. Heppel going out to superintend the works. He also, in conjunction with that accomplished engineer, made designs for the Carlisle Bridge, Dublin, in a well-known competition; and also for the bridge over the Brisbane, the metropolitan river of Queensland. The last engineering work in which Mr. Phipps was engaged, was the assisting of Mr. Robert Stephenson to remodel the historic cast-iron bridge over the Wear, at Sunderland. This interesting operation was carried to completion by Mr. Phipps, who fully described the work in the course of a series of lectures delivered before the School of Military Engineering, at Chatham, in 1873.

With the death of Robert Stephenson, Mr. Phipps' active career was brought to a close, although he was destined to survive his friend nearly thirty years. Having achieved a competence, he was able to lead a life of leisure, varied by occasional reports on matters wherein his opinion was sought; but for the most part devoting himself to the study of various recondite problems of engineering science. The movement of floating bodies, and the many elements affecting the propulsion of ships, were subjects to which he paid great attention; as were also the fundamental considerations determining the design of iron structures. Mr. Phipps was, however, a thoroughly "all-round" man, there being but few departments of engineering in which he was not an expert, as may be judged from his having been chosen to deliver the series of lectures on "Practical Engineering," at the Chatham Military School before referred to. He was a most indefatigable attendant at the meetings of the Institution, of which he was elected a Member on the 14th of April, 1840, and until a short period before his death, took a keen interest in the discussions, in which he was a recognized and respected participator. In addition to his important paper "On the Resistances to Bodies passing through Water,"[1] for which he received a Telford Medal and Premium in 1864, his contributions to the discussions occupy for citation alone a space of no less than three pages of the subject-matter index to the first fifty-eight volumes of Proceedings, while many of his later utterances are not recorded in that volume. His activity in this

[1] Minutes of Proceedings Inst. C.E., vol. xxiii. p. 321.

respect ranged over the whole field of modern engineering, the experience accumulated in his long career, coupled with his extensive and profound reading, conducing to render his participation in the debates of much value and interest.

BENJAMIN PIERCY was born at Trefeglwys, Montgomeryshire, on the 16th of March, 1827. He was the third son of Mr. Robert Piercy, who was well known in the counties of Montgomery, Denbigh and Flint as commissioner, valuer and surveyor in the inclosure of commons and waste lands, and who was also extensively engaged in the construction of public roads and other works, and in surveys and valuations under the Poor Law and Tithe-Commutation Acts. Mr. Benjamin Piercy, who was educated privately, at an early age entered his father's office, and soon became actively engaged upon important surveys and other work of varied description. About 1847, he became chief assistant to the late Mr. Charles Mickleburgh of Montgomery, who had a large practice as surveyor, land-agent and inclosure-commissioner, with whom he remained four or five years. During this period, as well as during the time passed in his father's office, Mr. Piercy devoted the whole of his leisure to the study of civil engineering and general railway practice. He had had the opportunity of travelling through every part of Wales, and had noted the necessity which existed for the establishment there of railway communication. He had not long to wait for an opportunity of participating in active work. The late Mr. Henry Robertson,[1] sometime M.P. for Shrewsbury, and subsequently for the county of Merioneth, engaged Mr. Piercy to assist him in making the parliamentary surveys for the Shrewsbury and Chester Railway. So much energy and attention did Mr. Piercy devote to the work, that he was the means of preventing the loss of a year in obtaining the Act for that line. He was afterwards employed under Mr. Robertson upon the plans and sections for the first Bill for a railway from Oswestry to Newtown; that Bill was not passed. Application was made to Parliament in a subsequent session, and Mr. Piercy was again engaged in the engineering, but upon that occasion, too, the Bill was not passed. It was in 1852, when he became the Engineer for the Red Valley Railway Bill for constructing a line from Shrewsbury to Minsterley

[1] Minutes of Proceedings Inst. C.E., vol. xciii. p. 488.

and Newtown, that Mr. Piercy's independent practice commenced. With characteristic energy and skill, he had within a very limited time prepared the parliamentary plans for deposit, but they were surreptitiously removed from the room which he occupied at a hotel in London, so that it was impossible to proceed with the Bill in the then ensuing session. In the following year, however, he duly deposited the plans for a railway from Shrewsbury to Welshpool, with a branch to Minsterley. Although strongly opposed at every stage, including Standing Orders, Mr. Piercy succeeded in carrying the Bill through both Houses, and it received the Royal assent. It was in the Select Committees on this Bill that he first made his reputation as a witness in Parliamentary Committees.

After this, he was engaged upon nearly all the projects for introducing independent railways into Wales, all of them meeting with fierce opposition; for several days consecutively he was as a witness under cross-examination by the genial Mr. Serjeant Merewether and other eminent counsel, but so little headway were they able to make against Mr. Piercy, that upon one occasion, when a Committee passed a Bill of Mr. Piercy's, Mr. Merewether held up his brief-bag and asked the Committee whether they would not give that too to Mr. Piercy?

Amongst the numerous railways in this country of which he was engineer are the following:—The Oswestry, Ellesmere and Whitchurch, the Oswestry and Newtown, the Llanidloes and Newtown, the Newtown and Machynlleth, the Welsh Coast Railways extending to Aberystwith, the Aberdovey, Barmouth and Pwllheli, the Vale of Clwyd, the Carnarvonshire, the Denbigh, Ruthin and Corwen, the Bishops Castle, the Mid-Wales, the Hereford, Hay and Brecon, the Kington and Eardisley, the Hoylake, and the Wrexham, Mold and Connahs Quay, with its extensions and branches.

The principal engineering works upon the railways above enumerated were as follow:—Upon the Oswestry and Newtown Railway, several important river bridges, comprising the crossing of the River Vyrnwy, and three crossings of the Severn; in these cases, the railway was carried over upon iron-plate girders of large span resting upon iron cylinders sunk to a great depth and filled in with concrete. There were also two fine stations, one at Oswestry, the other at Welshpool. The construction of the Newtown and Machynlleth Railway, owing to the mountainous nature of the country, involved some heavy work, *e.g.*, an open cutting about 120 feet deep at Talerddig, and several long skew

bridges over mountainous torrents, constructed with unusually massive masonry firmly bedded in solid rock foundations at great depth. Upon the Welsh Coast Railway was the crossing of two great estuaries, exposed to the sea, with tides of 16 feet range. One of these at Barmouth, about 2 miles wide, was crossed with iron girders resting upon screw piles, with an opening bridge to admit of the passage of sea-going vessels.[1] The other estuary crossing was near Portmadoc.

In 1862 Mr. Piercy was consulted by the Concessionaires of Railways in the Island of Sardinia, with reference to the construction of the railways for which they had obtained the concession, comprising about 250 miles of lines. The plans and sections, which had been prepared by Italian engineers, involved the construction of about 20 miles of tunnels and many heavy works of art, so that it was found impossible to get contractors who would be willing to build the railways within the limit of time allowed by the concession, and at a cost within the amount of funds available. Mr. Piercy re-surveyed the whole of the projected railways, and changed their proposed course, reducing very considerably the tunnelling and other heavy work, and he succeeded in designing a system of lines capable of construction at a practicable cost within the prescribed time. The Royal Sardinian Railway Company was thereupon successfully formed, having first obtained the adoption and acceptance of Mr. Piercy's plans by the Italian Government, and a contract was entered into with Messrs. Smith, Knight and Co. for the construction and completion of the railways accordingly. The works progressed, and some of the easier sections of railway were nearly completed, when the war broke out between Italy and Austria and stopped all further operations. Everything remained suspended until 1869. During the interval, the works sustained considerable damage from floods and otherwise. Mr. Piercy was again called in by the railway company to re-survey the lines and prepare new estimates for their completion. When these were finished, he negotiated on behalf of the company a new convention with the Italian Government; by this convention, which came into force in August, 1870, an increased annual kilometrical guarantee was obtained for the company, and it was agreed that the railways should be divided into two series, one called the "lines of the first period," the other, the "lines of the second period."

The "lines of the first period" comprised only the lines of the

[1] Minutes of Proceedings Inst. C E., vol. xxxii. pp. 163, 169.

plains left unfinished in 1865, of a total length of 197 kilometres; the "lines of the second period" were the more difficult lines over and along the mountains, 194 kilometres. The time allowed for completing the "lines of the first period" was extended to the 31st of December, 1874, after which, the company was to decide whether it would construct the "lines of the second period," or whether it would sell the undertaking to the Government. Mr. Piercy lost no time in taking energetic action on this new convention; for some months, he carried on the construction of the railways on behalf of the company, but subsequently the works were again let to a contractor, Mr. Piercy acting as engineer-in-chief, and early in 1872, the "lines of the first period," excepting one section of about 45 kilometres, were opened for public traffic, leaving only the construction of that section to fulfil the company's obligations under the convention of 1870.

The construction of the "lines of the second period" was subsequently proceeded with, and after almost endless difficulties from various causes, the junction of the "lines of the first period" with the "lines of the second period" was effected in June, 1880, and the whole were formally accepted, approved by the Government, and opened throughout early in 1881. As an acknowledgment of the great national service rendered by Mr. Piercy, he was created a Commendatore of the Crown of Italy, and the freedom of various cities in Sardinia was conferred upon him. Subsequently, it was decided to construct an extension of the system from the extreme north-eastern terminus of the line at Terranova to the Golfo di Aranci, a splendid natural harbour directly facing Civita-Vecchia, the port of Rome; the construction of this extension, about 27 kilometres, was also entrusted to Mr. Piercy; the works involved a heavy cutting of more than ½ mile in length, and over 40 feet deep through difficult strata. The cutting was completed within ninety days, and the whole line within seven months. Mr. Piercy also designed a mole and other harbour works at the Golfo di Aranci, which are now being constructed to his plans.

Supplementary to the main lines of railway in Sardinia, which are all of the standard 4 feet 8½-inch gauge, Mr. Piercy took advantage of his long residence in the island to study several series of subsidiary lines of the metre gauge to be feeders to the main system; his studies extended to nearly 2,000 kilometres of narrow-gauge railways, passing through difficult mountainous districts at an altitude, in several instances, of from 3,000 to 4,000 feet; for several of these lines, his plans were accepted by the company

and approved by the Government, and they are now in course of construction.

It was not in railways only that Mr. Piercy interested himself in Sardinia; he gave great attention to effecting agricultural improvements in the island; deserts and swamps were converted by him into perfect gardens by extensive drainage works, and the planting of many thousands of eucalyptus and other trees, so that places, formerly noted as hot-beds of fever, were rendered perfectly healthy; he also planted vineyards and orchards on a large scale. He acquired large estates, which he stocked with cattle, horses and sheep, of all of which he so improved the breeds that his stock attained the reputation of being far superior to any other in the island, and he gained many medals awarded by Government as well for cattle, horses and sheep, as for agriculture. He, moreover, did a good deal towards instructing the natives in good husbandry, which was before in a very primitive state. In short, Mr. Piercy's hand was pre-eminently visible in all improvements, and he was universally looked upon as a public benefactor, throughout the period of his connection with Sardinia, which extended over twenty-five years.

During Mr. Piercy's residence in Italy, he was an intimate friend of Garibaldi, who paid him frequent visits in Sardinia; and one of Garibaldi's sons was for some time one of his pupils.

In addition to the Sardinian railways, Mr. Piercy was employed upon other public works in Italy, notably a project for the canalization of the Tiber; he also prepared the plans for the Acqua Marcia, the great company by which Rome is now supplied with water. In France, he was the Engineer-in-chief of the Napoléon-Vendée Railway, a line which has been constructed and in operation many years, about 160 miles in length, from Tours, *viâ* Bressuire, to Sables d'Olonne, a well-known port and seaside resort on the Bay of Biscay. In India, he was the Engineer for the lines, about 90 miles in length, of the Assam Railways and Trading Company, Limited, passing through the tea-plantations in Assam, and connecting Dibrugarh, on the River Brahmaputra, with the coalfields at Makum, in the Naga Hills near the frontier of Burmah, where the company is working extensive collieries. These collieries were opened up under Mr. Piercy's direction, and he was engaged at the time of his death in taking measures for the working of the valuable petroleum deposits also belonging to the Assam Railways and Trading Company. He also took an active part in projecting an extension of the Assam Railway across the Burmah frontier, through the Naga Hills, south-eastward, to meet the railway now being con-

structed in Burmah northward from Mandalay; holding a strong opinion that the right way to obtain access to the interior of Burmah, and to pacify that country, was to connect the railway systems of India with the railways in Burmah, utilizing the Assam railways as the middle link.

To revert to the year 1881, when the Sardinian "lines of the second period" were completed; Mr. Piercy then again took up his residence in Great Britain, and purchased an estate, Marchwiel Hall, near Wrexham, with the intention of devoting himself to the resuscitation of the railways in North Wales, of which he had been the engineer before he went to Italy. He took them in hand financially as well as in the capacity of engineer; consolidating and re-arranging their capital accounts, and planning extensions, branches and improvements, so as to develop the valuable mineral resources of the districts through which they passed, and to bring to the lines their fair share of traffic. He found a ready ally in Mr. Henry Robertson, who had, before Mr. Piercy's departure for Italy, occupied a position antagonistic to the latter's Welsh railway projects, and the two became cordially associated in the common object of improving the industries of North Wales. Parliamentary powers were obtained by the Manchester, Sheffield and Lincolnshire Railway Company, for connecting the Wrexham, Mold and Connah's Quay Railway with Birkenhead, Liverpool and Chester on the north, by a bridge across the Dee at Connah's Quay, and powers were obtained for connecting the Wrexham line with the Cambrian Railways on the south, by an extension to Ellesmere, thus completing the North Wales railway system, and providing a new through continuous route, uniting Liverpool, Manchester and the North with all parts of Wales, South as well as North.

Mr. Piercy received many invitations to become a candidate for Parliament, but he determined to bide his time; had he lived he would doubtless have entered the House of Commons. He was a chess player of no mean ability, and a great advocate and patron of all manly games and intellectual pursuits. He laid out at Marchwiel Hall one of the finest cricket grounds in the kingdom; he was ardently fond of the game, and excelled in it. He was a Justice of the Peace for the County of Denbigh, his assistance in matters of County Government being highly appreciated for its eminently practical and original character. In private life, Mr. Piercy's tastes were simple, healthy and intellectual; he was a most agreeable companion, and he was much esteemed by his intimates for his generous and amiable disposition;

but his great characteristics were thoroughness, a habit of bestowing regard upon things which those around him would consider trifles, infinite capacity for taking pains, an extraordinary power of premeditation and forethought, thinking things out to the end, and mentally working out the result of even the smallest matter to which he put his hand, coupled with indomitable and unceasing perseverance and persistence in all which he undertook, but, at the same time, modest and unassuming to an unusual degree. Mr. Piercy was elected a Member of the Institution on the 8th of January, 1860. He died on the 24th of March, 1888.

ARTHUR POTTS, the second son of Mr. Henry Potts, of Glan-yr-Afon, Denbighshire, was born on the 23rd of June, 1814. He was apprenticed to Messrs. Mather, Dixon & Co., of Liverpool, where he was a contemporary of Mr. W. B. Buddicom, and other engineers afterwards destined to rise to note in connection with the establishment of the railway system. He was known to George Stephenson, who was constructing the Liverpool and Manchester Railway when young Potts was serving his time. Messrs. Mather, Dixon and Co. did a good deal of work for the early lines, and in this way Mr. Potts was thrown much in contact with Mr. Robert Stephenson, Mr. Locke, and Mr. Errington, and became a personal friend of each. Some time after completing his apprenticeship, Mr. Potts joined Mr. John Jones at the Viaduct Foundry, near Newton le Willows, which had a very prosperous career. Messrs. Jones and Potts employed about eight hundred men, and for several years were fully employed in making locomotive-engines for various railways, notably the Caledonian Railway. This latter line owed much to the Newton firm, for being about the year 1848 in great pecuniary straits, owing to the financial crisis caused by the unsettled state of the Continent, it was very much owing to the forbearance of Messrs. Jones and Potts that the great bulk of the company's creditors were prevented from taking hostile action. Had that been done the completion of the Caledonian line would have been deferred for years, and many a prosperous manufactory would have ceased to exist. The firm also executed stationary and marine-engine work. Mr. Potts did not take a large share in the practical management of the works; he did nearly all the travelling, but when at the works used to make frequent rounds of all the shops. He used to amuse the good fitters when he examined the work of their indifferent mates by trying to insert the edge of his pen-knife into

the joints of those parts of the engines supposed to fit closely. Mr. Potts was much liked by the men, and more especially by the drawing-office apprentices to whom he had always something pleasant to remark. In those days locomotive-engines were in great demand, at large profits, and Messrs. Jones and Potts were turning them out at the rate of about one engine a week. A strike, which lasted a considerable time, caused the firm great anxiety, but owing to the confidence that Mr. Brassey, Mr. Locke, and others had in the two partners, they did not suffer so much as might have been expected. Some of the men eventually gave in, but many of the best mechanics did not, and in many cases their places had to be filled up by indifferent workmen who were by no means efficient substitutes. Notwithstanding this, Messrs. Jones and Potts turned out some excellent work; the quality of the work in their engine the "Newton" was not surpassed by that of any other firm of the day. In 1852, offers were made by the London and North Western Railway Co. for the purchase of the Viaduct Works (without the machinery), and that company ultimately acquired the property, when Mr. Potts retired from business with an ample fortune. Thereafter, until his death on the 4th of April, 1888, Mr. Potts lived at Hoole Hall, Cheshire, and amused himself in horticultural pursuits, growing orchids, &c.; he also had a love for Alpine plants, and had collected a good many; he was much esteemed by his friends and neighbours for his frank and simple manner, his warm-hearted generosity, and the liberal views he took of his responsibilities as a county gentleman and Justice of the Peace.

Mr. Potts was elected a Member of the Institution on the 6th of December, 1870.

FRANK SALTER, younger son of the late Rev. W. A. Salter, of Amersham and Leamington, was born on the 19th of October, 1848. He was educated at Amersham and University College, London, where he gained the Andrews Entrance Exhibition (£25) for mathematics, and eventually graduated as Bachelor of Science, London, in 1868.

His apprenticeship was served in the workshops of the London and North Western Railway Company, at Crewe, from 1868 to 1870, and in 1871 (the second year of the Whitworth scholarship), he competed in the workman's competition in which he was successful. After this he had experience of the Newcastle engineering strike in 1871, being then with Messrs. Clark,

Watson and Gurney, followed by a short stay with Messrs. Gwynne, of Hammersmith. From 1874 until 1881, he was manager of Messrs. Bryan, Donkin and Company's works at Bermondsey, and on the reconstruction of that firm, he became one of the partners, acting as managing partner in the works, until the failure of his health in the autumn of 1887. With the exception of a short time in the summer of 1888, he was unable to resume work, and his illness terminated fatally on the 31st of December, 1888.

As a Student of the Institution, he contributed a paper on "Economy in the Use of Steam," for which he was awarded a Miller prize; this Paper was afterwards rewritten, enlarged and published by Messrs. Spon, under the above title. He was elected an Associate on the 12th of January, 1875, and transferred to Member on the 3rd of May, 1887. In conjunction with Mr. B. Donkin, jun., he communicated a Paper to the Institution, on some trials of a Rotative Pumping-Engine, and more recently a Paper on the Measurement of Water over Weirs, both of which were published in the Minutes of Proceedings.[1]

An extensive series of experiments on the small steam-engine now in the engineering laboratory of University College, London, was made by Mr. Salter, together with the late Mr. B. W. Farey, and Mr. B. Donkin, jun., in the years 1874–1881, the results of which were published in "Engineering" in November and December 1886.

The genial, thoughtful and hardworking character of Mr. Salter, with his kind and quiet disposition, gained him many friends in the works, as well as in the offices. A special feature of his character was a keen sense of honour, appreciated by all those with whom he came into contact in business. As an employer he was much respected, and his early death was greatly regretted, not only by his partners, but by all those under him.

BERNHARD SCHMIDT was born on the 13th of April 1828, at Prenzlau in Prussia. His father was Pastor of the Parish of S. Nicolaus in that town, his mother Adelaide von Raven, a daughter of Baron von Raven of the Ukermark.

Of six children Bernhard was the eldest son. He received his early education at the gymnasium of his native town. He was being carefully prepared for the University when the death of his father at the early age of 41, necessitated a change of plans, and he was removed to the Polytechnic School of Potsdam, to receive a

[1] Minutes of Proceedings Inst. C.E., vol. lxvi. p. 278; vol. lxxxiii. p. 377.

practical training as an engineer. On leaving this school he served an informal apprenticeship, first in a smaller workshop in Potsdam, and later with Mr. Spazier, an ironfounder and machinist of some note in Berlin. While in this establishment young Schmidt's intelligence and quick perception, and the uncommon excellence of his drawings, attracted the attention of Mr. Buckholz, who was attending to some engineering work in Berlin for the late Mr. I. K. Brunel, and who in 1848 brought him to England, and obtained for him an appointment in Mr. Brunel's drawing office, where he remained for about eighteen months; he then left to assist Mr. Charles Heard Wild in preparing the working drawings of Sir Joseph Paxton's design for the Great Exhibition Buildings of 1851.

When, after the close of the World's Fair, the scheme of the Crystal Palace was projected, involving the re-erection at Sydenham of the Exhibition Buildings on a greatly enlarged and improved design, Messrs. Fox and Henderson secured the services of Mr. Schmidt in preparing the detail drawings of the work, and on its completion he joined the staff of the Zealand Railway, for which Messrs. Fox and Henderson were the contractors.

Returning to England in 1854 Mr. Schmidt was immediately engaged by the late Mr. J. M. Rendel, Past President Inst. C.E., to assist in designing iron bridges for the new railways in India, of which Mr. Rendel was consulting engineer, and for other places.

Among these designs was one of a light and graceful arch to span the ornamental water in St. James's Park. On its submission to the Office of Works, however, objection was taken to the camber of the bridge, and the condition was imposed that the footway must be practically level. The result is seen in the existing "ugly suspension bridge." But the principal work on which Mr. Schmidt was engaged, while in the office of Mr. Rendel, was the design for the bridge to carry the East Indian Railway across the River Soane at Patna. The bridge consists of twenty-eight wrought-iron lattice girders, each of 150 feet clear span, resting on brickwork piers 12 feet wide, these piers being built upon wooden curbs shod with iron and sunk into the clay bed of the river to an average depth of about 30 feet. The total length of the bridge between the abutments is 4,530 feet, added to which there are smaller spans on each side forming the land approaches.

Compared with the iron and steel bridges of the present day these dimensions are not remarkable, but in many details of construction as well as in graceful appearance, the Soane bridge was a great advance on the railway bridges which had preceded it, and it has for more than thirty years well stood the test of the heaviest railway

traffic in India. The bridge (weighing approximately 3,500 tons) was constructed in this country, and its erection in India was entrusted to the late Mr. Samuel Power, an experienced member of Mr. Brunel's staff, with Mr. Schmidt for his assistant. But before the work of erection had very far advanced, Mr. Power was compelled on account of ill-health to leave India, and on the special recommendation of himself and of the late Mr. Turnbull, Engineer-in-chief of the Railway, Mr. Schmidt received from the Board full charge of the works with the rank of District Engineer. It was in the performance of his duties at the Soane bridge that Mr. Schmidt was thrown from his horse, and had his left foot so severely crushed that immediate amputation of the leg below the knee was necessary.

Mr. Schmidt remained in the service of the East Indian Railway Company until the completion of the line to Benares in 1862, when he accepted, from the Indian Public Works Department, an appointment as Executive Engineer of the first class, for service in Madras on the River Godavery improvement and part canalization. About two years were occupied in this work, when Mr. Schmidt returned to England, and on the recommendation of Mr. (now Sir) George B. Bruce, President Inst. C.E., he was appointed Resident Engineer of the then newly projected Berlin-Gorlitz Railway, which formed so important a line of communication for the German troops in the war of 1870–1. In 1867, on the completion of the Berlin-Gorlitz line, Mr. Schmidt was appointed Engineer-in-chief of the great North East Railway of Hungary, the construction of which occupied the next five years of his active life, and on the completion of the line he was called to Vienna to regulate the financial matters of the syndicate which had taken over from Dr. Strousberg the contract for the construction of the railway.

In 1874, after thirty years of arduous and unremitting toil, Mr. Schmidt retired from the profession, and took up his residence at Weimar, but his mind was of an order which could not endure idleness. From his boyhood he was an accomplished draughtsman and colourist, his portfolios were filled with water-colour sketches of the more remarkable places he had visited, all of them exhibiting vigorous and accurate drawing, and many of them harmonies of brilliant colour which might well excite the envy of a professional artist; but he now entered the studio of the famous German painter, Friedrich Preller, and pursued for several years with all the enthusiasm of youth the study of oil painting. He also (and particularly after the death of his great master) devoted his engineering knowledge and experience to the benefit of his adopted town. As an Alderman (Rathsherr) of Weimar, he evinced the

manager of this important undertaking, which at intervals employed more than two thousand men. Mr. Altoft Summers retired about the year 1858, and some years after Mr. Thomas Summers became a partner, the style of the firm being altered to Day, Summers and Company, and being destined to achieve a world-wide reputation. Mr. Thomas Summers had previously become well known in engineering circles by his contributions to the professional magazines, and had been invited by the Turkish and some other foreign governments to take pupils for training in marine engineering. He accepted those offers to a limited extent, particularly favouring Turkish pupils. He afterwards constructed the engines of several Turkish gunboats, as well as several lots of propelling-machinery for the Egyptian and other governments. He also designed and constructed the engines of some British gunboats, among them the "Pandora," which was afterward purchased by Mr. (now Sir) Allen Young, for the purpose of arctic exploration. On this occasion the "Pandora" was put into Mr. Summers's hands for a complete re-equipment for arctic work. Mr. Summers played an important part in connection with ocean steam-navigation, particularly as regards the Peninsular and Oriental, the West India, the Union, the Hamburgh American and the North German Lloyd Companies. He built steamers for the three first-named companies and engined many vessels for all of them, besides doing a large amount of work for the British and foreign governments, and for private owners. Among the fine mail steamers built at Northam were the "Nile," "Allemania," "Surat," "Syria," and "Hindostan"; while the 800 HP. engines of the West Indian mail steamer "Seine" were, when they were constructed some thirty years ago, considered to be of the first importance. At the commencement of his career the "Great Eastern" was found to be deficient in a number of minor details of machinery, &c., and was put under Mr. Summers's charge for alterations, during a period of six months, while in Southampton Water. When the compound-marine engine was brought into practical use, Mr. Summers urged upon the before-mentioned companies the advisability of converting their existing machinery to the compound system, and scores of engines averaging 3,000 HP. were altered by him to the then new and economical system. He was very successful in this description of work, and the repute of the Northam Ironworks has been maintained in later years in the process of converting compound into triple-expansion engines. Mr. Summers took great interest in the form of the screw-propeller, and where circumstances permitted would chip and file a propeller until it attained to a true helix with a smooth surface.

The Peninsular and Oriental, and other large companies, recognizing the value of his form of propeller, ordered many of the Southampton firm. His solicitude for details and for scientific principles becoming known in the United States, Messrs. Winans, about the year 1874, entrusted him with the building of the machinery of their two "Cigar Ships," which were designed to cross the Atlantic in six days. Special machinery of the most efficient kind was put in these vessels, and they obtained, for those days, very promising results. The owners, however, for ulterior reasons maintained secrecy as to the vessels, and in the meantime the pioneer "Greyhounds of the Atlantic," such as the "Arizona" made their appearance with their equally high speed and comfortable deck cabins, which were wanting in the cigar ships. The latter are still afloat in Southampton Water, awaiting their opportunity. It is interesting to note that their designers and owners were very sensible of the importance of surface-friction, and in addition to chipping and filing the propellers, the same process was applied to the entire submerged hulls of the vessels, which were flush-built and afterwards coated with black lead.

In the earlier part of his career, Mr. Summers invented and patented a steam-pressure gauge, of which he made a sufficient number to more than pay the expenses of patenting; but the appearance of Bourdon's gauge for higher pressures rendered Mr. Summers's instrument obsolete. Later, he patented his well-known sheer-legs for lifting very heavy weights; these speedily came into universal favour, and he constructed them for every civilized government in the world, as well as for private dock companies. Some of these were sufficiently powerful to lift the complete turret out of a ship of war.

In the early days of surface-condensation, when the Peninsular and Oriental Company had abandoned it on account of the effect of the fatty acids on the brass tubes, Mr. Summers introduced the plan of tinning the tubes, which was immediately resorted to, and has since been followed with complete success. It is unknown whether Mr. Summers was the actual inventor of this process, but in any case considerable credit is due to him for his efforts to promote its introduction. As an instance of the confidence felt in Mr. Summers's strict integrity, it may be recorded that when he was on the point of retiring from business, he was asked by the Peninsular and Oriental Company to look at the boilers of the newest addition to their fleet, which had failed on the vessel's maiden trip from the builder's yard to London. By the same post he received an invitation from the builders to act in a similar

capacity on their behalf. On informing the parties that he had been engaged by both, he at once received a reply from each to the effect that they would accept his decision, and begging him to act for both sides. Inspection of the boilers revealed the fact that the high pressure had caused leaks in nearly every part. Thereupon Mr. Summers rendered his decision against the builders and prescribed the alterations to be carried out. The award was cheerfully accepted, although it involved a cost to the builders amounting to the supply of almost entirely new boiler-shells.

In 1884 Mr. Summers retired from business, and thereafter occupied himself in various less exacting avocations. He became a director of the Southampton Floating-Bridge Company, of the Southampton and Isle of Wight Steam Packet Company, of the South Hants Waterworks Company, of the Southampton Chamber of Commerce, and a Governor of the Royal South Hants Infirmary. He was elected a Member of the Institution on the 1st of March, 1864, and was also a member of the Institution of Naval Architects. With rare professional attainments Mr. Summers united an amiability and kindness of heart that rendered intercourse with him a real pleasure. This typical Englishman died on the 22nd of March 1889, and his funeral was a quasi public one, at which all the more prominent of his fellow-citizens were represented.

JOHN PAGAN was born at Maxwelltown, Dumfriesshire, on the 21st of May, 1842. In 1860 he was articled for five years to Mr. George Mackay, County Surveyor of Invernesshire, with whom he remained, as pupil and assistant, for seven years. In 1867 he became an Assistant Surveyor to the Corporation of Preston, and held the appointment for two years, when he was promoted to a similar office under the Corporation of Bradford. His career at Bradford was a busy one, for it embraced the period of the important street improvements carried out during the years 1869–72, which quite transformed the leading thoroughfares of that borough. In 1872 Mr. Pagan became Deputy Borough Surveyor to the Corporation of Sheffield, and held the position until 1875, when he was unanimously, and without previous canvassing on his part, selected for the office of Borough Surveyor of Wakefield. As holder of this office he was responsible for several works of interest in municipal engineering, among the most important being the main sewerage extension of the borough, and ventilation and improvement of the outfall. In the early part of 1879 the office of Borough Surveyor of Bradford became vacant, and Mr. Pagan had

resolved to try and obtain the post, and so return to his old friends and congenial work in the cloth metropolis, but when on the point of sending in his application he was appointed Surveyor General to the Gold Coast. In May of the year mentioned he proceeded to the West Coast of Africa to commence his duties. On leaving Wakefield Mr. Pagan was the subject of a complimentary dinner, and presentation on the part of the Corporation officials, when a most generous appreciation was manifested of his labours in that borough. Of his work at the Gold Coast little need be said. He held the office of Surveyor General for nearly ten years, during which time he designed and carried out various public works of an important character which greatly benefited and improved the sanitary condition of the Colony. He fulfilled his duties with a conscientious and assiduous thoroughness that was, perhaps, unjust to himself, having regard to the treacherous climate. To this he ultimately became a victim, dying of fever at Accra, on the 13th of December, 1888, respected by all his brother officers. As a mark of esteem, they erected to his memory a monument in the graveyard at Accra.

Mr. Pagan was elected an Associate of the Institution on the 2nd of February, 1875, and on the reconstruction of that class in 1878 became an Associate Member.

PETER ROBERTS was born at Penzance, on the 3rd of April, 1846. At the age of sixteen he was articled for five years to Messrs. Harvey and Co., of the Hayle Foundry, and on the expiration of his pupilage he was sent by that firm to Norway, to superintend the erection of engines and machinery for the Bratsberg Mining Company. On returning to England, in December, 1867, Mr. Roberts was for a year similarly employed at the East London, and the Southwark and Vauxhall Waterworks, when he became an assistant in the drawing-office of Messrs. R. and W. Hawthorne, Engineers, Newcastle-on-Tyne, under Mr. F. C. Marshall, the managing partner. Here he remained until September, 1871, when he accepted a position in the Engineering Department of the Trinity House, under Sir James Douglass, the Engineer-in-chief. Mr. Roberts occupied this post for about four years, when he undertook a series of temporary engagements, successively with Mr. R. T. Longridge, the Engineer of the Manchester Steam-User's Association; Messrs. Mather and Platt, Engineers, Manchester; and Mr. Henry Rofe, Engineer of the Nottingham Waterworks.

In December, 1878, ill health compelled him to resign the latter post, and for the next four or five years he did little in his profession. In 1883, being restored to fairly good health, he was appointed Resident Engineer of the Helston Railway; but soon afterwards the works were suspended, and he then became assistant to Messrs. T. and C. Hawksley, inspecting machinery for the Barbadoes, and the Oxford City, Waterworks. After that Mr. Roberts had some desultory employment, in inspecting machinery and the like, but his health again failing, he died on the 25th of February, 1888.

Mr. Roberts was elected an Associate Member of the Institution on the 5th of February, 1884.

JOHN BURN ANSTIS DU SAUTOY, was a son of the Rev. Frederick du Sautoy, vicar of Mark, Somersetshire. He finished his education at Somerset College, Bath, where he gained several prizes for mathematics, &c., and in February, 1867, was articled for three years to Mr. Francis Fox, at that time Chief Engineer to the Bristol and Exeter Railway Company. On the expiration of his pupilage, Mr. du Sautoy remained in the employ of the company for two years, during which time he was engaged on the construction of the Cheddar Valley Railway; and had the superintendence of a railway opening-bridge of large dimensions over the River Parrett, at Bridgewater, and of the manufacture of the ironwork for the same at the Patent Shaft and Axletree Works, at Wednesbury. For more than a year Mr. du Sautoy had the inspection (as Resident Engineer for the Bristol and Exeter Railway) of the Devon and Somerset line, then being constructed by an independent company. On leaving the Bristol and Exeter Company, he was engaged as engineering agent to Mr. Blinkhorn, contractor for the Bristol Harbour Railway, and on finishing that work, he went in a similar capacity to the Birmingham and Harborne Railway, for Mr. George Bush, the contractor, and afterwards to Messrs. Thomas Nelson and Co., contractors, of York and Carlisle. By the latter firm he was engaged as engineer and manager for five years, and in that capacity had the sole charge of contracts on the North Eastern Railway, including extensive alterations at Hull, and the doubling of the main line between Brough and Saddlethorpe, on the Hull and Selby Railway; for the last two years of its construction he was in sole charge of the Leeds and Wetherby branch, where the works were of an extremely heavy nature. When this line was passed by Captain Tyler, the Govern-

ment Inspector, his report stated that "It was many years since he had inspected a railway so well and so ably constructed," and he especially commended the laying down of the permanent way.

On leaving Messrs. Nelson, Mr. du Sautoy did sundry work on his own account at West Bromwich and in London, subsequently returning to Messrs. Nelson for a short time, as manager of a large contract at Cardiff. He was afterwards employed in that town in Parliamentary work by the Rhymney Railway Company, and from that went to the Taff Vale Railway Company, in whose service he remained nearly two years, until November, 1885, when serious illness compelled him to relinquish work permanently. Quiet and retiring in manner, and unselfish and kindhearted in disposition, he made many friends, and his untiring industry, perseverance under difficulties, and love of his profession were prominent features in his character. He died on the 25th of February, 1889, after three and a quarter years of painful illness, at the age of forty years.

Mr. du Sautoy was elected an Associate Member of the Institution on the 1st of February, 1887, and was also a Fellow of the Geological Society.

GEORGE REAVELY TYNDALL, son of Mr. George Tyndall, of Tours, France, was born on the 17th of October, 1856. He served a pupilage of four years, from 1874 to 1877, to his father, who was the Chief Engineer of the Vendeen Railway, and by whom he was employed on the works of the line from Sables-d'Olonne to Tours. He was next, from 1877 to 1880, a pupil of Messrs. Stothert and Pitt, of Bath. On the expiration of this term, he became a member of Mr. Edward Easton's staff, and was engaged under that gentleman in investigating the waste of water occurring in the district of the Brighton Corporation Waterworks, and in the construction of the Herts and Essex Waterworks, after which he was employed on electric-lighting works in Manchester. In 1883 Mr. Tyndall proceeded to Brazil, as the representative of Messrs. Edward Easton and Ffolkes, to construct sugar-mills and accessories for the Capivary Central Company. On the completion of the undertaking, he remained on the spot to direct the working and to make some improvements in the machinery. He died at Capivary, of fever, on the 17th of November, 1888.

Mr. Tyndall was elected an Associate Member of the Institution on the 7th of February, 1882.

GEORGE NAYLOR VICKERS was born on the 14th of November, 1830. He received the ordinary classical education of the day; his technical studies being chiefly confined to metallurgical chemistry, in which he became extremely proficient.

He became a partner in the firm of Naylor Vickers and Co. in 1853, and when the business was merged into that of Vickers, Sons and Co., Limited, he became a Director of the latter Company, and continued to be so up to the time of his death, which took place in Paris on the 20th of January, 1889.

As he chiefly resided abroad, his attention was more devoted to the commercial interests of the Company (for which his extensive knowledge of European languages peculiarly fitted him) than to the technical management of the works.

He was elected an Associate of the Institution on the 23rd of May, 1865.

CAPTAIN HARRY BORLASE WILLOCK, R.E., the only son of Mr. William Borlase Willock, of Fairfield, Tenby, was born on the 6th of March, 1854. He was educated at Cheltenham College, where he gained the Junior Scholarship in 1868, and in the following year the Senior Scholarship.

From Cheltenham he passed into the Royal Military Academy, at the age of seventeen. On obtaining a commission in the Royal Engineers as Lieutenant, in 1872, he proceeded to the School of Military Engineering at Chatham, where he soon made himself a name for his peculiar aptitude for details of railway work.

In 1876 he went to Bermuda, where he served with the 10th Company, Royal Engineers, and was employed in connection with the works for the defence of the New Dockyard and Naval Anchorage. After serving there nearly two years, he obtained leave for the benefit of his health, he having been offered a passage home in H.M.S. "Eurydice." Fortunately he did not avail himself of this privilege, and thus was saved the fate which befel all the crew of that unfortunate vessel which sank off the Isle of Wight, in 1878.

Returning from Bermuda, Lieutenant Willock joined the 2nd Company, Royal Engineers, at Shorncliffe, and proceeded with it to South Africa in December 1878. There he served in the earlier part of the Zulu War with Colonel (now Major-General) Sir C. K. Pearson's column, and was present in the action at Inyezane, on the 22nd of January, and throughout the occupation of Etshowe. He was mentioned in despatches, *London Gazette*, 16th of May, 1879, and received the medal and clasp.

A comrade at Etshowe, Major D. C. Courtney, R.E., bears high testimony to his unwearied devotion to duty, and the value of his unfailing cheerfulness in the vicissitudes of a most arduous campaign.

On his return to England, Lieutenant Willock was appointed to take charge of the workshops at the School of Military Engineering; and from there he proceeded to the Works Department, Royal Arsenal, Woolwich, under Colonel (now Major-General) W. H. Noble, R.E. His knowledge of steel and iron, and of the construction of railways, made him most useful in the particular duties assigned to him. Under Lieutenant Willock a considerable portion of the Arsenal railways were relaid, conducing greatly to facilitating the different transit arrangements among the various manufacturing departments.

On the outbreak of the Egyptian War, in 1882, Lieutenant Willock was appointed to assist in the Railway Transport, and prior to embarkation was engaged at Woolwich Arsenal in collecting railway material and plant, and loading it for shipment. He sailed for Egypt in August 1882, and superintended the unloading of the stores at Ismailia. In the performance of this work Lieutenant Willock acted in turns as stationmaster, guard, platelayer, engine-driver, &c. He assisted Lieutenant-Colonel D. A. Scott, R.E., when in charge of the railway-terminus at Ismailia. Later, Colonel Scott proceeded to Zag-a-Zig, and Lieutenant Willock was left in charge at Ismailia during the rush of traffic to Cairo, and at the conclusion of the campaign collected and accounted for all railway stores. For these services he received the Medal and Bronze Star. Returning to England at the end of 1882, he was placed on the staff of the Inspector of Iron Structures, at the War Office, and there assisted in the designing and construction of all machinery required in connection with the coast defences, and in the supply of material for, and general supervision of, military railways in this country, in Egypt, and the Sudan; for the latter service he was officially commended by the Inspector-General of Fortifications.

On Major English, R.E., accepting the appointment of Superintendent, Royal Carriage Factory, Captain Willock succeeded him as Inspector of Iron Structures. In this capacity, among other work, he completed the erection and tests of the 112-ton hydraulic traveller at Shoeburyness, and designed the details of the 250-ton pontoon sheers, now in course of construction. He acted as Secretary to the Committee on the preparation of the "Military Railway Manual," and also to the "Committee on the

preparation of Instruction for the Care and Maintenance of War Department boilers." In April 1884 he read a Paper before the Statistical Society, on "English Express-Trains in 1871, compared with those of 1883," which was much commended. He died at his father's house at Tenby, on the 6th of February, 1889, after a very short illness. He was elected an Associate of the Institution on the 13th of January, 1885.

Captain Willock's characteristics were comprehensiveness of idea, and great accuracy of detail. His mind seemed to grasp at once the ulterior object of an undertaking, and he was most careful in carrying out the details. His early death robbed the Service of one of its most promising men, and his friends of a bright and genial companion.

*** The following deaths have occurred, or been made known, since the 22nd of February last, in addition to some of those included in the foregoing notices:—

Members.

HINDMARSH, THOMAS; *born* 9 September, 1827; *died* 8 February, 1889.

LESLIE, Hon. HENRY HAWORTH; *died* 15 March, 1889; *aged* 43.

MCCONNOCHIE, JOHN; *born* 9 October, 1823; *died* 28 March, 1889.

MOORE, WILLIAM; *born* 20 November, 1834; *died* 19 May, 1889.

PEACOCK, RICHARD, M.P.; *born* 9 April, 1820; *died* 3 March, 1889.

SIMPSON, JAMES; *born* 10 January, 1829; *died* 11 May, 1889.

SPICE, ROBERT PAULSON; *died* 11 May, 1889; *aged* 75.

STANFORD, WALTER HALSTED CORTIS; *born* 27 November, 1840; *died* 18 May, 1889.

STILEMAN, FRANCIS CROUGHTON; *born* 26 May, 1824; *died* 18 May, 1889.

TURNBULL, GEORGE; *born* 2 September, 1809; *died* 26 February, 1889.

Associate Members.

FREND, WILLIAM ARTHUR; *born* 22 April, 1858; *died* April, 1889.

LEATHER, SAMUEL PETTY; *born* 8 April, 1823; *died* 20 February, 1889.

LEUPOLD, HUGO; *died* 14 April, 1889.

SCOTT, WILLIAM HEWLETT; *born* 15 October, 1858; *died* 23 April, 1889.

WALLACE, DAVID; *born* 18 October, 1847; *died* 5 May, 1889.

Associate.

LEE, HENRY; *born* 31 August, 1823; *died* 1 March, 1889.

Information respecting the life and works, the career and leading characteristics, of any of the above, is solicited, to aid in the preparation of future Obituary Notices.—SEC. INST. C.E., 27 *May*, 1889.

Sect. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

A New Water-Level. By P. Kahle.

(Zeitschrift für Vermessungswesen, 1888, p. 183.)

A tube of thick glass, ½ inch to ¾ inch wide, is bent and melted together into the form of a rectangle 7¾ inches long and 4¾ inches broad. Before being closed, it is half filled with coloured alcohol. The water-level made in this way is an improvement on the ordinary ⊔-shaped instrument, in which when transported, the tubes must be emptied or supplied with stoppers. In making an observation, the surveyor places his eye in the line of the two surfaces of the liquid, and the intersection, with the staff of this line of sight, gives the reading required. The instrument is held in the hand, so that no tripod is required, and in many cases the levelling-staff may be dispensed with.

The Author gives a number of results to show the accuracy that can be attained in hand-levelling. This method was found particularly advantageous in determining the altitude of some crystal-caves in a wild part of the Alps, where the irregularities of the surface precluded the use of a base-line for trigonometrical levelling. The total height above the starting-point was 1,050 feet, and a portion of the ascent was up inclines of 30° to 48°. The total error on returning to the starting-point was 1·31 foot. Considering the irregularity of the ground, and the fact that a dense fog prevented the staff being read at greater distances than 10 yards, it is evident that in this case the method was a convenient and trustworthy one.

Tests of the accuracy of the closed water-level were made along a road from Kahla-Lobschütz to the Leuchtenburg, a distance of 3 kilometres (1·86 mile). Accurate spirit-levelling showed the terminal points to have a difference in level of nearly 230 metres (754 feet). The results were as follow:—

Bench-mark.	Spirit-levelling.	Hand-levelling		
		By Eye.	With Staff.	
Kilometre-stone . 0·0	0·0	0·0	0·0	0·0
„ . 0·5	38·0	37·6	37·8	37·7
„ . 1·5	111·0	110·9	110·6	111·0
„ . 2·5	158·7	159·0	158·7	158·7
„ . 3·0	226·5	227·0	226·5	226·5
No. of sights . . .	200	141 + 1·4 m.	224	276
Time occupied . .	5 hrs.	1 hr. 25 min.	1 hr. 50 min.	2 hr. 16 min.

The approximation of the results of the hand-levelling to the true values in this Table exceeds that which could be obtained by careful barometrical observations. The Author is of opinion that the closed water-level may be advantageously used in many topographical surveys, in setting out small field-railways, roads, or watercourses, for determining the thickness of strata, and for measuring heights in districts where difficulties of transport preclude the use of the ordinary instruments. A closed water-level of the dimensions given may be purchased for a couple of shillings.

B. H. B.

The Teredo and other Timber-Pests.

By R. H. Hammersley-Heenan, M. Inst. C.E.

(Paper read at the Meeting of the South African Philosophical Society, Nov. 28, 1888.)

Greenheart (*Nectandra rodiæi*), and the Sneezewood of South Africa (*Pteroxylon utile*), have long enjoyed the reputation of resisting the attacks of marine worms, but the Author has discovered positive proof that both of these woods, under certain conditions, can be ruined by the *Teredo* and by the *Chelura terebrans*. (*Limnoria t.* is not known to occur in South African waters.)

About the year 1885 Mr. J. S. McEwen, then district engineer on the railway from Port Elizabeth to Uitenhage, noticed that the sneezewood piles of a bridge over a tidal stream not far from Zwartkop's station were diminished in section close to the low-water mark. On minute examination, it was found that the teredo had attacked the piles to such an extent that he was constrained to recommend their removal and substitution by iron. The Author exhibited a piece of one of the piles referred to, in which the work of the teredo could be very easily traced.

In 1878 the Port Elizabeth Harbour Commissioners had two jetties constructed from the designs and under the superintendence of Sir John Coode, V. P. Inst. C.E. For the most part wrought-iron was used, but it was decided that the seaward ends, known as the V-heads, should be of greenheart, and with this material, excellent of its kind, the work was carried out. Having lately to make a detailed inspection of this jetty, the Author noticed that which at first seemed to be signs of decay in one of the horizontal pieces, and on cutting into it with an adze found it to be completely honeycombed for about an inch deep with the tunnels of the teredo. On further examination it was found that all the horizontal timbers, at low-water mark, had been attacked in a like manner. In the vertical pieces and piles it was noticed that though the worm had entered them, its progress was small as compared with the horizontal pieces. The timber frame placed as a fender outside the iron portion of the jetties was next examined. The Author there found not only the teredo, but, in vast numbers, the destructive

little creature known as the *Chelura terebrans*, which invariably commences its destructive work at the ends of the timber, or where one piece comes into contact with another. In this way the chelura, although the actual area destroyed by it is comparatively small, becomes more injurious to a framed structure than does the teredo. Since his first inspection the Author has made numerous examinations of these works, and is convinced that before very long the question will have to be considered of replacing the timber work, which cost, for the two jetties, £25,000.

F. G. D.

On the Expansion of Portland Cement.

By Léon Durand-Claye and Paul Debray.

(Annales des Ponts et Chaussées, vol. xiv. 1888, p. 810.)

The experiments detailed in this Paper were undertaken in order to ascertain the amount of expansion of Portland cement mortar. The test-pieces were of square section, 2 feet 7·1 inches (0·80 metre) in length, and 0·47 inch (0·012 metre) in width. They were made upon a marble slab, between two pieces of metal. When sufficiently set, they were removed from the mould and placed in a glass tube, closed at the bottom and open at the top. To the upper end of the rod of cement a small fork was sealed, upon which a lever rested in such a manner that the expansion was multiplied ten times upon the scale. An illustration of the apparatus used is given, and the results are embodied in a series of graphic tables. One set of experiments was made with cement which had been mixed with calcined magnesia, and subsequently re-burnt. The expansion of this cement was considerable, and it was noticed that the increase of length was more rapid in summer than in winter. When samples of cement were immersed in water containing 0·6 per cent. of sulphate of magnesia, the expansion was more marked than when they were exposed to the action of river-water alone. In a series of comparative experiments made with normally and imperfectly-burnt Portland cement, it was found that the latter increased more rapidly in volume. When, however, a dilute solution of magnesia was substituted for river-water, the ratio of expansion was reversed.

W. F. R.

Influence of the Working-Velocity on the Tensile Strength and Extension of Annealed Copper Wire.

By Fritz Connert.

(Der Civilingenieur, 1888, p. 585.)

The object of the experiments recorded by the Author was to ascertain the effect of the time occupied in applying the load, or,

as he terms it, the working-velocity, on the tensile strength of copper wire, this material being selected on account of its suitability for such investigations.

The working-velocity, or velocity of loading for a prismatic test-piece, the Author defines as the sum of the increments of stress, and of extension occurring in one second, both expressed in metres. The stress must be given in lengths, and the extension as a percentage of the length of the test-piece.

To express the stress in this way, the so-called stress-length (*Belastungslange*) B is introduced; this is defined as that length of the prismatic test-piece which would have the weight necessary to produce the observed stress.

$$B = \frac{l}{g} P_x,$$

where l is the length of the test-piece, g the corresponding weight, and P_x the load. The extension

$$\delta = l \frac{z}{100},$$

where z is the percentage of elongation.

To eliminate the influence of l and obtain an expression varying only with the strength of the piece, the Author further introduces the equivalent breaking-length (*Reisslange*) R, which is the length of the test-piece which would have the weight necessary to produce the breaking-stress. Then the working-velocity

$$v = \frac{B + R \frac{z}{100}}{t},$$

where t is the duration in seconds of the experiment up to the moment when the load P_x is attained. Both B and R are quantities independent of the particular dimensions of the test-piece, and determined only by the nature of the material.

When fracture takes place, B = R, and the above formula becomes

$$v = \frac{1{,}000 \, R \left(1 + \frac{z}{100}\right)}{t},$$

when the metre and second are the units of space and time.

The nature of the testing-machine used by the Author is such that the extension of a single spiral spring measures both the stress and elongation of the test-piece, so that for a uniform motion of the spring the sum of the two components of the working-velocity in the unit of time is constant.

When the stress, as is usual with short and thick test-pieces, is

expressed in kilograms per square centimetre, the formula for the working-velocity takes the following shape:—

$$v = \frac{1{,}000\left(\frac{k_1}{\gamma} + \frac{k}{\gamma}\,\frac{z}{100}\right)}{t},$$

where k_1 is the stress at any moment during the test, k the breaking-stress, and γ the weight of unit-volume of the material.

From the observed breaking-stress, elongation, weight, and length of each piece tested, the equivalent breaking-length and working-velocity was calculated.

From the actual stress diagram a modified diagram for an ideal test-piece, having a length equal to the equivalent breaking-length, can be constructed. This figure is independent of the particular dimensions of the piece, being determined only by the quality of the material.

The testing-machine was worked either by a small hydraulic motor or by a gas-engine (according to the power required), through gearing which reduced the speed.

The times occupied in making a test varied from 10,700 to 4·9 seconds, corresponding to a working-velocity of from 0·3365 metre to 801·25 metres per second.

Breaking-stress and extension both increased with the working-velocity; the Author ascribes this to an augmentation of the radial pressure, perpendicular to the longitudinal axis, between the molecules, and finds that the influence of the working-velocity on the equivalent breaking-length (representing the breaking-stress) can be expressed by the formula

$$R = 0{\cdot}625\, v^{0{\cdot}05} + 2{\cdot}154,$$

in which the constant 2·154 corresponds to the ultimate strength pure and simple, at an extremely low working-velocity.

For the relative extension, a similar expression is found,

$$z = 1{\cdot}7054\, v^{0{\cdot}12} + 26{\cdot}346.$$

All the pieces of copper wire tested were thoroughly annealed and cooled in water.

The experimental results are given in a tabular form in the original, which is accompanied by illustrations in the text, and plates. G. R. B.

Workshop Chimneys. By EDMUND CORDIER.

(Bulletin de la Société de l'Industrie Minérale, 1888, vol. ii., p. 535.)

This exhaustive Paper of eighty-five pages, of which it is impossible to give more than an outline, is divided into six sections.

Section 1 considers the theoretical proportion of chimneys to provide a given draught as modified by the nature, weight, and temperature of the issuing gases, and the heat abstracted from them for useful purposes (*e.g.* by a boiler) during their passage through a flue or through the chimney proper, and concludes with a comparison of the relative useful effect of a chimney and a fan.

Section 2 gives the calculations necessary to determine the height and the area of the passage.

Section 3 discusses the outline, method of construction, proportions of the plinth, of the shaft proper, and of the capping, foundations, crushing-strength of materials, strengthening by hooping and bonding, and the disposition of lightning-conductors, and gives full particulars of the construction and erection of a wrought-iron chimney at Creusot. The total height of this chimney was 279 feet, its diameter 23 feet at base and 7 feet 6 inches at top, and its total weight 80 tons, exclusive of the masonry foundation, which was carried 3 feet 3 inches above the ground level, and weighed about 300 tons. It was built in successive rings, each 4 feet 1 inch high, the thickness varying from $\frac{9}{16}$ inch at the base to $\frac{1}{4}$ inch at top. The nine lower rings were formed of eight plates each, the upper ones of four plates each. The base was encircled by a massive angle-iron bolted to the foundation. For the first seven rings the contour was of a curvilinear outline, with a regular taper from that point to the capping. The eight lower rings were lined with firebrick.

The flying scaffold used for the erection consisted of a central wrought-iron tube of 7 inches diameter, provided at the bottom with four radial wooden cross-bars or arms, so clamped that their length could be adjusted to suit the varying diameter of the chimney, and, carrying the internal platform. These arms rested on angle-brackets riveted to the interior of the plates, and for greater safety were secured to them by dowel pins. The upper part of the central tube carried four cross-arms or jibs, each consisting of a pair of timbers stiffened by raking struts from the central tube. From their outer ends was slung the exterior circular platform, consisting of a pair of angle-iron rings, to the outer of which was riveted a plate-iron fence, while the inner was provided with T iron stanchions. Radial bearing-timbers resting on these rings, and adjustable endways to suit the varying diameter of the chimney carried the platform, leaving an annular space just sufficient for hoisting the plates. This was effected by a rope passing over an adjustable pulley fixed on each jib in turn, and carried down the central tube to a snatch-block fixed at bottom of the chimney, from which it was led away some little distance to a crab driven by a portable engine. Signals were given from the platform by a wire and gong. The same crab and rope were used to raise and lower the workmen by means of a skep, which, however, travelled inside the chimney. As each successive ring was fixed and riveted up, two pairs of bars were laid across, from which the scaffold was slung by four jack-screws furnished with ratchet-

collars, and was thus raised high enough to take a bearing on the next set of angle-brackets. The scaffold complete weighed about 4 tons, and the heaviest plate about 8 cwt.

When the sixty-eighth and last ring was fixed, the outer platform was lowered by means of four crabs and ropes, one to each jib. The plates had received one coat of paint in the workshop and one when fixed, and a third coat was applied during the descent of the platform, the lightning-conductor being fixed at the same time. The jibs and upper part of the central tube, which was made in two lengths with a flanged joint, were then dismantled, a single pulley was fixed at top, and the whole lowered.

The whole operation, including dismantling, occupied seventy days, or say one day for each ring, and was conducted without the slightest accident or hitch. The total cost, including erection, but not including the foundation, was about £1,600. The stability of the chimney has been severely tested by several violent storms.

Section 4 considers very fully the effects of wind both on the draught and stability of the chimney, and lays down the general law that the stability of a round chimney is about one-fifth greater than that of a square one when the diameter of the former equals the side of the latter, and refers to five chimneys at the Commentry colliery, which were destroyed by a storm on the 20th of February, 1879. These were square chimneys, and in most of them the force of the wind and the direction of their fall was diagonal, and not perpendicular to the flat side.

Section 5 considers the question of deterioration and repairs, and describes the flying scaffolds designed by Mr. Broussas, of Lyons, and Messrs. Brown and Porter, of Liverpool, the ladder system employed in Germany, the rectification of a chimney at Bingley, near Bradford, and of two others on the Blind system by sawing the joints, and a method of dismantling a chimney without destroying the bricks, as carried out by Messrs. R. M. and J. Bancroft. A cast-iron box with an airtight flap-valve cushioned with gutta percha was placed at the bottom, and on it an airtight wooden shoot, measuring ½ inch wider each way than the bricks themselves, was fixed. The resistance of the air retarded the fall, and the bricks were shot into the box without injury. When the box was full the operation was suspended while it was emptied, and the upper and now useless part of the tube sawn off. This shoot cost £6.

The Author quotes from the *American Architect* the description of the removal of a chimney 88 feet high, 6 feet 4 inches in diameter at base, and 4 feet 11 inches at summit, weighing 130 tons.

Section 6 gives full particulars of several chimneys from actual practice.

The Paper is illustrated by three plates and by numerous sketches and diagrams.

W. S. H.

The New Dome of the Parish Church of Gattinara, built by Comm. Guiseppe Locarini.

(L'Ingegneria Civile e le Arti Industriali, 1888, p. 149.)

The church was built at the beginning of the present century, and the dome has lately been added in substitution of the original roof. The plan of the space to be covered was an irregular symmetrical octagon, of which the smallest diameter was 70 feet 10 inches, and the sides were alternately 40 feet 3 inches and 21 feet 8 inches long. It had been intended to adopt another kind of roof, and, before the dome was decided on, the walls for its support had been built, their thickness at the springing being only 2 feet, so that the problem of raising a dome from these supports was a difficult one. After due consideration, Mr. Locarini decided to construct a framework of iron and fill it in with brickwork. Eight iron ribs rise, one from each corner of the octagon, to a height of 42 feet 4 inches, and meet in an upper octagon 10 feet in diameter formed of iron bars. The ribs are tied together horizontally by six other octagonal sets of bars. At the middle of each of the longer sides is another rib reaching from about the mid-height to the top, and from the middle of each short side is a rib reaching from the bottom to about two-thirds of the height; two similar ribs to these last are placed in each of the longer sides, making a total of twenty-four ribs. They are, of course, all curved so as to give a correct outline to the octagonal dome. This is surmounted by a light lantern. With the exception of the lower halves of the ribs, which start from the springing, the whole of the framing is formed of rolled-iron joists.

It was essential that the brickwork should combine with the necessary solidity and stability the greatest possible degree of lightness. The first 8 feet in height was built as a solid wall up to the first horizontal bars 1 foot 8½ inches thick. From this level, a rib of brickwork, enclosing each of the iron ribs, is built up to the base of the lantern. The intervening spaces are filled in with brickwork in three thicknesses, the inner and outer fill up the whole width of each space. Each is half a brick thick. The inner layer is built of vertical and horizontal lines of bricks with vacant spaces between them. This is the general principle adopted, the details being explained in the Paper by drawings. If the brickwork had been built solid throughout, there would have been 615 cubic yards, but this quantity is reduced by the vacant spaces to 569 yards, of which 66 yards are built with hollow bricks.

W. H. T.

Arch Bridge over the Cserna, Hungary. By F. Pfeuffer.

(Allgemeine Bauzeitung, 1889, p. 9.)

This is a small wrought-iron arch bridge of a light and elegant design. The span is 100 feet, the width 10 feet, the rise of the arch 16 feet, and the depth of the lattice-ribs 2 feet. Vertical posts, about 7 feet apart, put upon the arch, support the platform. The arch rests on the abutments by means of pivots. The calculation of strains is according to a combined graphical and analytical method first published in outline in Winkler's "Lehre von der Elasticität und Festigkeit, Prag, 1867," and more completely communicated by Dr. T. Steiner, in the "Allgemeine Bauzeitung," 1874, pp. 21, 33, 49.

M. A. E.

Formulas for the Weights of Bridge-Trusses.

By A. J. du Bois, Jun. Am. Soc. C.E.

(Transactions of the American Society of Civil Engineers, 1888, p. 179.)

The formulas, which had been proposed by the Author in a previous Paper,[1] had evoked a valuable discussion, in the course of which some objections were urged as to the complexity of his method, the inaccuracy of his assumptions in the case of long struts, and the omission of any proper provision for the weight of such details as pins, eyes, and secondary bracing. But the Author believes it possible to construct a rational formula that shall express in general terms the weight of any truss in which the sectional area of the members has been determined by the usual calculations; and to effect this object with the requisite degree of correctness and of simplicity, he proceeds to complete his former investigation, introducing certain modifications to meet the objections referred to.

For the sake of simplicity, he neglects any separate treatment of the live load, and deals only with a uniform load W per foot lineal, which is made up of the following items:—

w_1 = a uniform load equivalent to the live load.
w_2 = the weight of floor, stringers, floor-beams, &c., per foot lineal.
w_3 = the weight of the wind bracing per foot lineal.
w_4 = the weight of the main trusses per foot lineal.
w_0 = the additional weight of the details above mentioned.

As regards the live load, it is explained that the equivalent uniform load, W_1, is the load that would produce the same moment, at the centre of the span, as that due to the actual wheel-loads of

[1] Minutes of Proceedings Inst. C.E., vol. xc. p. 470.

the engine and train, whatever they may be; and, by way of example, the values of W_1, for different spans, are calculated for an assumed train weighing 3,000 lbs. per foot, and headed by two "typical" tender-engines. In the same way, the weight W_2 of the floor-system, and the weight, W_3, of the wind-bracing, may be found for each case by actual measurement, although they are here taken from the Table, and empirical formulas given in the Author's previous Paper.[1]

The useful load having thus been found or estimated, the problem in hand is to find the weight of the main trusses, $W_4 + W_0$; the working-stress in tension and in compression being R_t and R_c respectively, while the latter varies with the radius of gyration of the strut.

Summating, as before, the products of the length and the sectional area of each member in a Warren girder, the weight of the entire lower chord is given by $\frac{5\, W\, N\, p^3 (N^2 - 1)}{18\, R_t\, d}$, in which N is the number of panels, p the panel width, and d the depth of the truss.

For the series of diagonals in tension, the Author now finds the weight to be $\frac{5\, W\, (p^2 + 4\, d^2)\, N}{24\, R_t\, d}$. These two expressions will also apply to the upper chord, and to the diagonals in compression, if in each case R_c is substituted for R_t.

Adding these four quantities, and dividing by the length of span $N\,p$, the total weight of the truss per foot, exclusive of details, is given by—

$$w_4 = \frac{5\, W}{18\, d}\left[\frac{(N^2 - 1)\, p^2}{R_t} + \frac{(N^2 - 1)\, p^2}{R_c} + \frac{0\cdot 75\, (p^2 + 4\, d^2)\, N}{R_t} + \frac{0\cdot 75\, (p^2 + 4\, d^2)\, N}{R_c}\right].$$

For the sake of abbreviation, the Author writes—

For all tension members $T = (N^2 - 1)\, p^2 + 0\cdot 75\, N\, (p^2 + 4\, d^2)$.
For the upper chord $C = (N^2 - 1)\, p^2$.
For the diagonal struts $S = 0\cdot 75\, N\, (p^2 + 4\, d^2)$.

There results:—

$$w_4 = \frac{5\, (w_1 + w_2 + w_3 + w_4 + w_0)}{18\, d}\left[\frac{T}{R_t} + \frac{C}{R_c} + \frac{S}{R_s}\right]$$

in which R_s is the working-stress proper for the diagonal struts; and from this:—

$$w_4 = (w_1 + w_2 + w_3 + w_0) \div \left(\frac{3\cdot 6\, d}{\frac{T}{R_t} + \frac{C}{R_c} + \frac{S}{R_s}} - 1\right)$$

[1] Minutes of Proceedings Inst. C.E., vol. xc. p. 470.

The unit-stress in the upper chord will, in practice, be determined by $R_c = \dfrac{\mu}{1 + \dfrac{p^2}{250\, r_1^2}}$; and in the diagonal struts it will be

$R_s = \dfrac{\mu}{1 + \dfrac{p^2 + 4\, d^2}{4 \times 125\, r_2^2}}$,[1] the stress μ being usually taken at 8,000 lbs. per square inch in the case of wrought-iron; while the tensile stress R_t is also taken at the same value.

Therefore:—

$$w_4 = (w_1 + w_2 + w_3 + w_0) \div \left[\frac{3 \cdot 6\, \mu\, d}{\dfrac{\mu}{R_t} T + C + S + \dfrac{C\, p^2}{250\, r_1^2} + \dfrac{S\,(p^2 + 4\, d^2)}{500\, r_2^2}} - 1\right]$$

To arrive at an approximate estimate of r_1^2 and r_2^2, which denote the square of the radius of gyration in the upper chord and in the diagonal struts, the Author finds that the average of practical examples is fairly given by the empirical formulas:—

$$r_1^2 = \frac{(N - 1)\, p^2}{100}, \text{ and } r_2^2 = \frac{(N - 1)\,(p^2 + 4\, d^2)}{200}$$

Inserting these values, the expression for the weight of the main truss per foot lineal, but exclusive of the details, is brought into the form—

$$w_4 = (w_1 + w_2 + w_3 + w_0) \div \left[\frac{3 \cdot 6\, \mu\, d}{\alpha\, p^2 + \beta\, d^2 + \dfrac{\alpha\, p^2 + 4\, \beta\, d^2}{5\,(N - 1)}} - 1\right] \quad (1)$$

in which $\alpha = (2\, N^2 + 1 \cdot 5\, N - 2)$ and $\beta = 6\, N$.

These values of α and β apply to the Warren girder, while for a single-intersection Pratt truss the values would be $\alpha = (2\, N^2 + 3\, N - 2)$, and $\beta = 3\,(2\, N - 4 + \frac{11}{N})$; and for a double intersection Whipple truss, they would be—

$$\alpha = 2\left(N^2 + 3\, N - 10 + \frac{12}{N}\right), \text{ and } \beta = 3\left(N - 2 + \frac{16}{N}\right).$$

It still remains to ascertain the weight per foot of the minor details W_o, and, assuming that formula (1) gives correctly the net weight of the members, the Author deduces the extra weight of the details by comparison with certain actual weights of trusses quoted by Mr. Pegram, and thereby arrives at the empirical formula $W_o = \dfrac{N\, d}{3} + A$, in which $A = 0 \cdot 875\, N\,(12 - N) + 6$.

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[1] In these expressions the radius of gyration (r) is in inches, while the lengths p and d are in feet.

Finally, the weight of the truss is given by :—

$$w_4 + w_0 = \frac{(w_1 + w_2 + w_3) + L\,w_0}{L - 1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

in which L is used to denote :—

$$\frac{3 \cdot 6\,\mu\,d}{\alpha p^2 + \beta d^2 + \dfrac{\alpha p^2 + 4\beta d^2}{5(N-1)}}$$

The Paper contains tables of the calculated values of A and of α and β, as well as the estimated weights of floor W_2; and the correctness of the principal formula is tested by comparison with numerous examples.

For rapid and easy calculation, the Author proposes, as an alternative to the rational formula, the following empirical expression for the total weight of ironwork in a bridge of ordinary (American) construction, including the floor system, viz.—

$$\text{Total weight of iron in pounds} = \frac{a + b\,l}{\dfrac{c}{l} - 1}.$$

In this formula l is the span, while a, b, and c are constants depending upon the class of traffic, viz.—

		Plate Girders.	Truss Spans.
Mogul engines with train 1,820 lbs.	a	124,720	301,900
	b	3,415	562
	c	585	518
Consolidated engines with train 2,240 lbs.	a	393,880	303,000
	b	14,848	1,160
	c	2,040	578
"Typical" engines with train 3,000 lbs.	a	228,612	293,343
	b	7,774	1,167
	c	1,110	549

The formula applies to trusses up to 320 feet span; and comparing it with a number of deck-plate bridges up to 80 feet, Pratt trusses from 80 to 150 feet, and Whipple trusses from 150 to 320 feet span, the results are shown to coincide within a small percentage.

T. C. F.

The Construction of the Poughkeepsie Bridge.

By J. F. O'Rourke, M. Am. Soc. C.E.

(Transactions of the American Society of Civil Engineers, 1888, p. 199.)

At the point where the Hudson River is crossed by the Poughkeepsie Bridge, the width from shore to shore is about 2,600 feet; and in the original charter it was stipulated that the bridge should

be carried across this width in a single span. The construction of such a span was, however, regarded by practical men as verging upon the impossible; and the charter was amended so as to permit the erection of four river-piers, dividing the length into five spans of about 500 feet each; while the clear height of the lower chord was stipulated to be 130 feet above high water.

In this form the scheme was supported by the Pennsylvania Railroad Company, and the work was commenced in 1876 by the American Bridge Company, who put in the cribwork foundations of the first two river-piers; but shortly afterwards the work was suspended until 1886, when the Union Bridge Company commenced operations under a contract to complete the entire structure according to a modified design in which the cantilever principle was introduced in some of the spans.

In the new design, the existing foundations of the first two river-piers were utilized, and the width from shore to shore was divided, as before, into five spans, of which the second and fourth are crossed by lattice-girders having a uniform depth of 75 feet and a length of 525 feet from centre to centre of piers. These trusses are extended at each end as cantilevers, forming part of the first, third, and fifth spans, which have a width of 546 to 548 feet (centre to centre), and consist of cantilevers projecting from each pier and carrying an intermediate girder between them. The pier at each shore is therefore the central support of a cantilever which on one side projects over the river-opening, and on the other is carried back, as a land-span, to a distance of 201 feet, where it is secured to an anchorage; the total length of the seven spans between the anchorages being 3,093 feet.

The work is further prolonged by an extensive viaduct over the town of Poughkeepsie; and the double line of railway is carried throughout upon the tops of the main girders at an elevation of 212 feet above high-water.

The Paper is chiefly concerned with the methods adopted in executing the work, including the foundations of the river-piers and the erection of the superstructure.

The pier-foundations are, in general, carried down to a depth of 124 feet below high-water, through 70 feet of mud, clay, and sand, where they rest in a bed of strong gravel overlying the rock; and the foundation of each pier was got in by means of an open grillage of cribwork, divided into pockets or cells from which the material was excavated by dredging from above water.

Each crib has a total height of 104 feet, the top being finished at 20 feet below high-water; while in plan it forms a rectangle 100 feet × 60 feet. The surrounding walls of this rectangle are 10 feet thick at the sides and 9 feet thick at the ends, while a longitudinal partition wall, 16 feet thick, is carried along the centre line, uniting the end walls, and leaving two rectangular openings of 82 feet × 12 feet, one on each side of the central partition. Each of these main walls is formed by an inner and an outer skin of timber 2 feet thick, composed of 12-inch timbers laid horizontally, while the

space between the skins is filled with weighting material. At the bottom, the main walls are tapered to a cutting-edge, the triangular section being 20 feet in height, and formed of solid timber in the manner of an American caisson.

The two long openings 82 feet × 12 feet, are again divided into cells 10 feet × 12 feet by six transverse bulkheads of timber running completely through the crib, and 2 feet in thickness. The crossing lines of timber walling are laid together without halving the timbers, by laying the alternate courses with breaking joints—thus in one course the longitudinal timbers, and in the next course the transverse timbers run through the intersection. The drift bolts are 1 inch round by 30 inches long, four hundred and fifty to each course; the force required to draw a bolt of this diameter, driven into a $\frac{15}{16}$ hole, being found to be about 422 pounds per lineal inch.

The first few courses of the cribwork were either built upon ways and launched, or were built upon the ice and cut in; and the building was then continued alongside a wharf until the crib drew as much water as was available in the river. It was then towed out and anchored in position, and the weighting pockets being loaded with gravel to bring the top to a convenient height above water, the building was continued until it was imbedded in the mud.

The material was then excavated by dredgers working in each of the fourteen cells or compartments, whose united area, however, was only about one-fourth of the entire area of the crib, so that considerable masses of the material were necessarily left under the inclined sides of the cutting edges; and as a consequence the wells were often carried 30 feet below the base before the crib would sink; and although the sinking was tolerably regular at first, yet when the side friction increased with the increasing depth, the sinking was very intermittent, the crib sometimes going 10 feet at a jump, and sometimes getting out of plumb in its descent.

In towing out and anchoring the floating crib, great difficulties were experienced in handling this rectangular vessel of 5,000 tons and drawing 52 feet of water, in the face of a powerful current. The anchors employed were simply cubical cribs 6 feet × 6 feet inside, and 6 feet high, and filled with broken stone. To moor the crib securely, it was ultimately found necessary to place eight of these anchors on the up-stream side, six on the down-stream side, and four on each flank; and success was only finally achieved when the working strength of the cables was nearly equal to 1,000 tons. When the crib was placed in position, the dredging, sinking, and building proceeded at the rate of about 1 foot per day; and when sunk to the full depth, the pockets were filled with concrete of native cement. For this purpose a couple of barges or "scows" were moored over the crib; and the concrete, after being mixed by machinery carried in the barges, was deposited in each cell by closed boxes containing 1 cubic yard, which were unlatched by a tripping line. By this method 400 cubic yards were deposited in ten hours, and the crib was thus filled to within 2 feet of the top,

the remaining part being filled with broken stone and levelled by divers.

The next operation was to prepare and float into position a timber caisson, which was placed upon the top of the crib, and within which the masonry of the pier was commenced.

Each of the masonry piers has a length of 87 feet, and a width of 25 feet; and as these dimensions are much less than those of the cribwork foundation, the pier was easily adjusted in true position upon the crib, even if the latter had settled considerably out of line or level in the process of sinking.

The masonry piers are carried up to a height of 30 feet above high-water, and are faced with ashlar in courses of 2 feet 9 inches to 1 foot 10 inches in thickness, with a hearting of Portland cement concrete containing 1½ barrel of cement to the cubic yard. Large blocks of stone are also imbedded in the concrete. The entire construction of the pier progressed at the rate of 125 cubic yards per day.

Upon the top of the masonry piers, steel towers are carried up to a further height of 100 feet, carrying upon their summits the bed-plates for the support of the main-girders, whose lower chords are at an elevation of 130 feet above high water.

The towers having been completed, the method adopted for erecting the superstructure of the bridge was, in outline, as follows:—

(*a*) The parallel lattice-girders crossing the two spans of 525 feet (which were described as forming the second and fourth from the shore) were first built *in situ* upon continuous timber staging.

(*b*) The land spans of 201 feet, extending from each shore pier to the anchorage, and forming the tail end of the first and last cantilevers, were also built upon staging, and anchored down.

(*c*) The three cantilever spans of 546 feet were then erected by carrying out the cantilevers piecemeal from each pier, until the construction was closed in the centre.

(*a*) The timber staging for the erection of the two river spans was in itself a work of considerable magnitude. The platform on which the main girders are placed is supported by twenty-two trestles, each trestle having a height of 118 feet, and standing upon a group of piles whose length is 130 feet; while the upper platform carries a moving timber scaffold, or traveller, extending to a further height of 95 feet, for the erection of the upper portion of the ironwork; so that the total height of the timber-work from the pile-shoes to the top of the moving scaffold is 343 feet.

The cross-section of the travelling scaffold may be described as forming an inverted trough, embracing the whole width and height of the finished truss, with sufficient working space on all sides, its interior width being 38 feet, while its interior height is 82 feet. The scaffold runs upon four lines of rails, *i.e.*, one pair of rails under each leg; and each leg consists of two timber posts 10 inches square, one over each wheel-frame. These posts are united by bracing 3 inches × 8 inches, and are spaced 8 feet apart at the

bottom, and 11 feet apart at the top, where they are framed together with the cross-piece of the trough, which is formed as a timber lattice girder 13 feet deep, and 62 feet in extreme length.

The framework of the inverted trough being thus constructed, four such frames are erected at distances of 22 feet apart, and united by longitudinal waling timbers and diagonals of 1¼ inch round iron, and by the wheel-frames at the base of the scaffold, which thus form a traveller 66 feet in length running upon 32 wheels. The heaviest piece to be lifted by it was something over 20 tons.

The main staging carries not only the lines of way for the traveller above described, but also an interior track of 19 feet gauge for the use of the hydraulic riveter, and again another interior and central track of 4 feet 8½ inches gauge for the transport of materials. For these purposes, the main trestles of the stage are formed with a top width of 57 feet, each trestle consisting of eight posts of whole timber splayed out at the bottom to a width of 90 feet, and united by cross-bracing.

Each leg of the trestle stands upon a nest of three piles, 130 feet in length, driven into the bed of the river to a depth of 115 feet below high-water, and there are 528 of these piles under each stage. The piles were formed in two lengths, united without a scarf by dressing the abutting ends to an octangular shape 12 inches in diameter, and fishing them with eight long splices of spruce timber 20 feet × 5 inches × 4 inches, fastened with 8-inch spikes driven 1 foot apart. The working load on each pile is about 5 tons.

(*b*) For the erection of the land spans of the terminal cantilevers, the staging was carried up to the level of the upper chord, or 212 feet above high-water.

(*c*) The cantilever spans were built out from each pier by means of a different kind of overhead traveller, which was itself a movable cantilever composed of two main trusses 118 feet long, with a uniform depth of 24 feet, in which the longitudinal chords and vertical posts were of timber, and the diagonal ties of wrought iron. The rear end of the cantilever, for a length of 68 feet, is provided with a heavy floor and supported upon wheel-frames fitted with six wheels on each side; and the carriage runs upon rails on the top of the finished trusses of the bridge, while the overhanging length of 50 feet serves for the building out of the bridge cantilevers, the heavy pieces being lifted by derricks fixed at the front end of the wheel-frames.

The cantilevers are thus built out from each pier, until they leave a space of 212 feet between their approaching ends, which space is crossed by an independent girder. But each end of this central girder was designed with a stiff lower chord, and the terminal panels being temporarily connected to the cantilever ends by an adjustable joint, they served for the moment as extensions of the cantilevers, supporting the travellers in their forward progress until they met in the middle, and were enabled to put in the central panel of the intermediate girder. The temporary end con-

nections were then released so as to leave the girder in the tion of a suspended intermediate span.

The Paper is accompanied with numerous illustrations of the bridge, and of the plant employed in its erection.

T. C. F.

Employment of Mild Steel in Railway Bridges.

By P. F. A. Hallopeau.

(Revue Générale des Chemins de fer, vol. i., 1889, p. 61.)

In this, and a preceding Paper, the Gagnières viaduct, having three openings, is described and discussed. The Author, at the same time, deals with the general properties of mild steel (*fer fondu soudant*), and its adaptability for the material of railway bridges. The steel should be of great purity, having no foreign matter other than carbon and manganese. It appears to be estab-

Bridges of Iron and of Steel.

Bridges.	Resistance per Square Inch. — Elastic Limit.	Resistance per Square Inch. — Rupture.	Extension in 4 inches.	Formation of Rivet-holes.	Rivets.
	Tons.	Tons.	Per cent.		
Iron bridges . . .	11·43	26·67	6	Punched	Iron.
Steel bridges—					
Military, for railways, 1882	12·70 to 13·33	27·94 to 29·84	20 to 12	Drilled	Steel bolts.
Road bridge, Rouen .	13·97	31·75	18	Punched and drilled	Iron.
Bridge over the Braye	15·24	27·94	24	Do.	Steel, 24·13 tons, 28 per cent.
Viaduct of Coulain Court Street, at Paris-Montmartre .	..	28·57	20	Do.	Iron.
Bridge over the Rhone, Lyons	15·24	29·84	24	Do.	Steel, 24·13 tons, 28 per cent.
Mild steel bridges—					
Viaur viaduct . .	15·24	26·67	20	Do.	Iron or steel.
Road bridge, Arene, 1886. . . . . Lyons Railway Company	16·51	26·67	20 long. 18 across	Do.	Iron, 22·86 tons, 18 per cent.
Iseron bridge, 1887 . Lyons Railway Company . . . . Gagnières bridge, 1887 Lyons Railway Company	15·24 long. 13·97 across	26·67	25 long. 18 across	Punched	Mild steel, 22·86 tons, 30 per cent.

lished, that the proportion of carbon should not exceed 0·2 per cent.; and that of manganese, at the most, 0·3 per cent. Steel having a silky fracture is preferable to that of a granular fracture. The results of fracture have been found as follows:—

	Silky.	Granular.
Breaking weight	26 tons.	23½ tons.
Extension in 4 inches (100 millimetres)	30 per cent.	20 per cent.

The preceding Table summarizes the general conditions of the material which has been specified for various steel bridges in France, since the year 1882.

From this Table, it appears that mild steel has been selected, and that the quality was milder and milder until 1886, when the Lyons Railway Company arrived at the employment of very mild steel (*fer fondu soudable*). The following are the specified characteristics for 1886 and 1887:—

		1886.	1887.
Elastic limit		16·51 tons {lengthwise. across.	
Breaking resistance . . .		26·67 ,,	26·67 tons.
Extension	lengthwise . .	20 per cent.	25 per cent.
	across	18 ,,	18 ,,

It is notable that, according to the latest specification, the rivet-holes are simply punched to the final size. It is held that the metal around the hole is partially annealed by the heat of the rivet when placed.

D. K. C.

New Experiments on the Flow over Weirs. By H. Bazin.

(Annales des Ponts et Chaussées, vol. xvi. 1888, p. 393.)

Several successive weirs were established on the same canal, down which a steady flow of water was maintained. This gave data for calculating the relative coefficients of different weirs. The absolute coefficients are determined if the coefficients for one weir have been ascertained beforehand.

Apparatus for experiment.—The water was taken through sluices from the canal of Burgundy, near Dijon. The water first entered a masonry chamber, 15 inches by 4 inches, and passed afterwards into a canal 15 metres long, 2 metres wide, and 1·6 metre deep, at the end of which was the standard weir. From this the water passed through a canal 200 metres long with vertical sides. It was constructed of concrete covered with cement. For taking the water-levels chambers were formed in the side of the canal, usually 5 metres above each weir. The levels were taken from floats in the chambers which actuated a dial hand. The levels were checked by the use of hook-gauges.

Standard Weir.—The crest was 1·135 metre above the bottom

of the canal, and was formed by an iron plate $\frac{1}{4}$ inch thick. The weir length was equal to the canal width, so that there was no side contraction. A recess was formed in the canal side below the weir, to admit air under the sheet of water flowing over the weir. The coefficients for this weir were determined by measuring the water in the tail-canal, a dam being formed at the end. The chief difficulty was determining the level in this canal, where a wave-motion was set up which lasted some time. The results obtained were these. Let, as usual,

$$Q = m\, l\, h \sqrt{2\, g\, h} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (1)$$

be the formula for flow over the weir. Then the data of the experiments furnished values of the coefficient m. For the greater heads it was necessary to shorten the weir, cheeks of timber being used, so that the side-contraction was suppressed as before. The following are some of the values of m obtained:—

Head in Metres.	m.	Head in Metres.	m.	Head in Metres.	m.
0·05	0·4485	0·25	0·4259	0·45	0·4299
0·10	0·4336	0·30	0·4266	0·50	0·4313
0·15	0·4284	0·35	0 4275	0·55	0·4327
0·20	0·4262	0·40	0·4286	0·60	0·4341

These results are then compared with those of Fteley and Stearns, with which they closely agree.

Comparative Experiments on Weirs of Different Heights.—When it is wished to take account of the velocity of approach, h is replaced in the weir formula by $h + a\,\frac{u^2}{2\,g}$, u being the mean velocity in the channel above the weir, and a a coefficient not well determined hitherto, but about 1·5. The formula then becomes—

$$Q = \mu\, l\, h \sqrt{2\, g\, h} \left(1 + a\, \frac{u^2}{2\, g\, h}\right)^{\frac{3}{2}} \quad . \quad . \quad . \quad . \quad . \qquad (2)$$

In this form μ is for the same discharge less than m, and since $\frac{u^2}{2\,g\,h}$ is small:

$$m = \mu \left(1 + \frac{3}{2}\, a\, \frac{u^2}{2\, g\, h}\right) \text{ nearly} \quad . \quad . \quad . \quad . \quad . \quad . \qquad (3)$$

But

$$u = \frac{Q}{l\,(p + h)},$$

where p is the height of the weir above the bottom of the canal. So that there may also be written—

$$m = \mu \left[1 + k\left(\frac{h}{p + h}\right)^2\right] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

To determine these coefficients weirs like the standard weir, but of heights of 0·75, 0·50, 0·35 and 0·24 metre, were established in the canal, and the heads on these weirs were ascertained for given heads on the standard weir. Seven series of experiments were made with these weirs. In all these m increases as the height of the weir diminishes. A discussion of the results leads the Author finally to the equations:

$$m = \mu\left(1 + 2\cdot 5\,\frac{u^2}{2\,g\,h}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

$$m = \mu\left[1 + 0\cdot 55\left(\frac{h}{p + h}\right)^2\right] \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

where μ is given in the following Table:—

Head in Metres.	μ.	Head in Metres.	μ.
0·05	0·4481	0·40	0·4144
0·10	0·4322	0·50	0·4118
0·20	0·4215	0·60	0·4092
0·30	0·4174	..	..

Values of m calculated thus for each of the weirs are compared with the experimental values, and found to agree within 1 per cent., except for the weir 0·24 metre high, for which the divergence is a little greater.

W. C. U.

Regulation of the Moldau and the Elbe. By FRIEDRICH BÖMCHES.

(Wochenschrift des österr. Ingenieur und Architekten-Vereines, 1888, p. 355.)

This Paper gives an account of a trip made on the above rivers on the 21st of September last, with the object of ascertaining what progress had been made with the various regulation works from Prague on the Moldau, to Herrnskretchen on the Elbe (about 100 miles), since the last visit of inspection in 1884, and to arrange for carrying out such further improvements as might appear to be necessary.

Under the Elbe Act of 1881 it was decreed that a depth of

2 feet 9 inches at lowest water-level should be maintained in the section Hamburg-Leitmeritz, and 2 feet 3 inches from Leitmeritz to Melnik, but the inspection of the river in 1884 led to proposals for deepening these sections to 4 feet 7 inches and 4 feet 1 inch respectively at low-water; and as regards the Moldau, the condition of things was more unfavourable, and necessitated the construction of extensive and important works in view of making a port at Prague worthy of its position as a capital city. The result of the inspection in September last showed that the works on the Moldau were for the most part completed, with the exception of some dredging and blasting, which could not be carried out on account of exceedingly high water-levels. In addition to the above works, the following, which were not provided for in 1884, have been carried out, viz., the construction of a training-dam on the left bank of the river, and dredging for the purpose of improving or reducing the rapids at Lieben and Klecanek, and the regulation of the section from the Wrbnoer Ferry to the junction of the Moldau with the Elbe at Melnik, by building four training-dams and the formation of an entirely new channel. The works that could not be completed on account of the high water-levels, were blasting and dredging at Troja, estimated to cost £6,450, and at Rostok £2,950; but when these shall have been finished, together with blocking out a creek at Podhabla on the left bank, and another on the right bank at Podhor; also widening the river channel at Husinec and Lettek, and reducing it at Mulhausen, Luzec, &c., the Moldau will then for its entire length possess the advantages of a fully-regulated river with depth and fall suitable for navigation.

As regards the Elbe, the works proposed in 1884 have been mostly completed, and the following supplemental costly works have been carried out, viz., the construction of a training-dam on the left bank between Liboch and Podeplitz, and the improvement of the river by training-dams and dredging from Launken downwards. The total cost of the regulation works is given as follows:—

	Proposed in 1884.	Supplementary.	Total.	
	Florins	Florins	Florins.	
On the Moldau . .	474,777	85,778	560,555	
„ Elbe . .	391,137	249,452	640,589	
Grand total .	865,914	335,230	1,201,144	=about £100,000

W. H. E.

Cutting away the Cazeau, Nord, and Verte Islands in the River Gironde. By G. Richou.

(Le Génie Civil, vol. xiii., 1888, pp. 375, 389, 1 plate and 3 woodcuts.)

These works, together with the lowering of some shoals in the channel, form a portion of the improvement works in the Upper Gironde, and in the Garonne below Bordeaux, undertaken with the

object of enabling large vessels to reach Bordeaux at any time. The navigation-channel between the islands and the right bank, just below the confluence of the Garonne and Dordogne, has a depth of only 7½ feet at low tide; but the new channel will have a minimum depth of 10 feet at the lowest stage of the river, and a depth of 14¾ feet in the central 246 feet of width over the site of the existing shoals. The works involve 15,170,000 cubic yards of earthwork, and an estimated expenditure of £672,000. Rock has been encountered at one shoal, after it had been lowered about 13 feet, which will necessitate the use of special appliances. The works at Cazeau Island offer the chief features of interest at present, necessitating the removal of 10,725,000 cubic yards of earthwork, which is being effected partly by an excavator and partly by dredgers. A trench, 13 feet deep, is formed by the excavator under shelter of the bank left between the trench and the river; and the excavations are conveyed in wagons by locomotives to form an embankment alongside the new cut, as an endless band which had been constructed for this purpose, over 2,300 feet long, worked with too much friction, resulting in frequent stoppages. As the excavator progresses, water is admitted successively into sections of the trench, and dredgers complete the excavation of the trench, to a depth of 33 feet below the surface. Of the five dredgers employed, three are bucket-dredgers, with an Allard distributor, and two are cutting suction-dredgers. The Margaux and the Cantenac bucket-dredgers, of 120 HP., discharge their material, by means of an Allard distributor, and a centrifugal pump, through floating iron tubes, 1 foot in diameter, with leather joints. As the material dredged is sticky blue clay, an auxiliary pump is placed on a barge alongside the dredgers, and each machine discharges about 11,000 cubic yards per month, to a distance of 985 feet, at a height of 13 to 16½ feet. The Parlepen bucket-dredger of 200 HP., running 16 hours per day, delivers from 13,100 to 14,400 cubic yards per month, the same distance, through floating tubes, with an auxiliary pump half way along. The two cutting suction-dredgers are of the type patented by Messrs. Vernaudon. The Cazeau dredger has its suction-pipe hinged at the side of the barge near the bottom, the position of the pipe being regulated by chains and pulleys fastened to its lower extremity, and attached to the end of the barge, so that the pipe can be put at any angle, or raised horizontally along the barge, when the barge is to be moved. A set of cutters, moved by gearing from the barge, is fixed radially on an axle placed at the end of the frame carrying the pipe, and beyond the mouth of the pipe, so that the cutters draw the material they detach towards the pipes. The centrifugal pump for drawing up the dredgings is placed at the bottom of the barge, reducing the effort of suction to the difference in density between the charged water drawn up the pipe and the surrounding water. This dredger has a suction-pipe 1 foot in diameter; and, with a force of 40 HP., it can discharge from 10,500 to 11,800 cubic yards of material per month, through

floating tubes, to a distance of 985 feet, at an elevation of 16½ feet, without any auxiliary pump. The Eureka dredger of the same type as the previous one, but with various improvements, is described in detail with illustrations in the second article. The suction-pipe of this dredger, 1¾ foot in diameter, is placed in a central well of the barge, and enters a central longitudinal recess when raised horizontally; it is guided in its motion by a beam moving on hinged slides, which gives it greater stability and rigidity than in the previous dredger; and the action of the cutters is under more direct control. This dredger, working in the same clayey sand as the Cazeau dredger, and under the same conditions of discharge, dredged 39,000 cubic yards per month. The motive force can be raised to 120 HP.; and this dredger is worked by four men, whereas the bucket-dredgers above mentioned, with their auxiliary pumps, require seventeen men. The average proportion of solid material raised by the suction-dredger, when working in sticky clay, is 10 to 12 per cent., but it reaches 40 per cent. in clayey sand. At a trial, the contractors succeeded in delivering the material at a height of 2 feet 3½ inches, to a distance of 985 feet, without any auxiliary pump. It is anticipated that, under the existing conditions, the work can be completed in five years, which is less than half the remaining time allotted.

L. V. H.

Ice-Barriers in the Danube. By Gottlieb Fänner.

(Wochenschrift des österr. Ingenieur und Architekten Vereines, 1888, p. 301.)

The details given in this Paper are the results of actual observations made by the Author in the Vienna canal and the Danube, and they confirm Hagen's theory, that in running streams ice begins to form when the temperature of the whole water falls to 0° or below it, and that the formation first takes place where the velocity is least, that is on the bottom or bed; for in walking along the Vienna canal, with about 2 feet depth of water in it, he found the bed so covered with ice that he could hardly keep his balance. This anchor ice is described as of a gelatinous or spongy nature, which rises on being touched, and rises also of its own accord when the mass has attained a certain size; and such ice it is stated constitutes by far the greatest portion of the ice that is seen on the surface of a river. Under sufficiently low temperatures ice is formed directly on the surface and also on the banks; and under certain conditions these unite with the particles rising from the bottom until at last, in intense cold, almost the entire river section may be filled with such ice, which is here called *Tosteis.*

It is mentioned that in boulder or gravel-bearing rivers, the bed is generally of an undulating form, and in high water-levels the surface forms a straight line of uniform slope or declivity, but that

as the level of the water sinks, the surface water line changes also, and in low water-levels, at which time ice-runs mostly occur, the longitudinal section of the water surface is no longer a straight line, but is formed of S shaped lines alternating with horizontal ones. At those places where the water passes over the *furth* (that is, the ford or shallowest part) there is the strongest current, while in the sections between the *furths*, that is, in the deepest parts, the current is small, and it is these parts which contribute most materially to the increase of ice, for when the ground-ice floating down from above reaches these parts, it rises to the surface, because there the velocity is reduced. At each succeeding deep part the ice mass becomes greater, till at last it is as thick or thicker than the depth of water at the *furth*, and there the ice barrier or block stands fast, causing a heading up of the water, and thus keeping back the ice floating down from above, while at the same time the ground-ice is continually rising up from below, and hence the accumulation of ice barriers is extended further up stream.

It is stated that ice-runs are very speedily formed, if the temperature suddenly fall to 12° or 15° below zero (Centigrade) along a great section of river with low water-level, but if the temperature be only $-4°$ or $-6°$, they do not occur till after several days' continuance of such cold, and with long continued temperatures of 2° or 3° below zero, no ice block has ever yet been formed in the Danube.

In this Paper are given sections of different parts of the canal, taken in 1880 and 1881, showing the thickness of the top ice or ice-kernel, as it is called, and the relative proportions of anchor ice and water below, and two of these sections, taken at the same spot in February 1880 and January 1881 respectively, show these ratios to be about 4 : 1. Diagrams are also given showing water-level, temperature, and ice-run during the occurrence of ice blocks in 1879–80, and 1887–88, and these indicate that ice-runs commenced at temperatures of 4° and 6° below zero respectively.

The Paper concludes with the Author's statement that until he had made these experiments in the Vienna canal, he was like most people ignorant of the fact that below the top ice-kernel there was such a vast quantity of anchor ice; and he adds that observations in the Danube itself produced the same results, which were again confirmed by Mr. Berger's soundings at Nussdorf. W. H. E.

Excavations for the Locks on the Panama Canal.[1]

By MAX DE NANSOUTY.

(Le Génie Civil, vol. xiii., 1888, p. 403, 4 woodcuts.)

The substitution of locks, with lifts of from 29½ to 36 feet, for the original scheme of a level canal,[1] necessitated rapid and precise excavations simultaneously at the several sites, which were

[1] Minutes of Proceedings Inst. C.E., vol. xcii. p. 446.

put in hand directly after the adoption of the new scheme. Four principal methods have been undertaken, namely, (1) excavation by pits; (2) excavation with large plant, and lifting with cranes; (3) large excavation, and removal by inclined planes; (4) excavation removed by inclined planes, and by cranes. Excavation in a pit has been specially carried out at lock No. 2, where as many navvies as possible work in the excavation, forming a large pit; and the material is removed by two movable 4-ton steam-cranes on the top, with skips holding $1\frac{3}{4}$ cubic yard, and discharged into wagons alongside. In the second method, two sets of lines branch off from the main line, one set descending into the cutting, and the other set serving for removing the material; and a trench is first excavated, which is subsequently enlarged by small plant or by excavation; and the material is removed by the aid of cranes with skips. In some cases, especially at locks Nos. 4 and 5, the main line was laid in the centre, and a line for the cranes was placed on each side, between which and the main line two trenches were excavated; and the central block is then removed by carrying down a double line of way, for conveyance and for cranes, into one of the trenches, and excavating all along the face in the ordinary way. This system is rather more costly than opening out a single trench; but the excavation proceeds more rapidly. The cranes discharge from 20 to 50 skips, holding $1\frac{3}{4}$ cubic yard, per working day. By the third method, adopted at six of the locks, the excavation is commenced over its whole width; the material is conveyed in small wagons to the base of the inclined planes, placed slanting on the slopes at about every 130 feet; and the small wagons are pulled up the inclined planes by steam-winches at the top, and either pushed directly to the tip, or their contents discharged into regular wagons drawn by locomotives. Each winch draws up about 65 cubic yards of material per day. At some of the sites, particularly locks Nos. 3 and 4, the central excavation is carried out in a trench, by the aid of cranes, whilst the side excavations are effected by the help of inclined planes and winches, an arrangement which gives good results. All the cuttings for the locks are kept dry by centrifugal pumps placed at the top of the slopes. L. V. H.

Corinth Ship-Canal.[1] By ARMAND SAINT-YVES.

(Annales des Ponts et Chaussées, 6th series, vol. xvi., 1888, p. 392, 2 plates.)

All the vessels trading between the Mediterranean ports of France, Spain, Italy, and Austro-Hungary, with Greece, Turkey, Asia Minor, the Lower Danube, and the Black Sea, are obliged to round Cape Matapan, which necessitates their going 2° of latitude to the south, and the same amount to the north again. By the

[1] Minutes of Proceedings Inst. C E, vol. lxxxv, p 447.

cutting through of the isthmus of Corinth, the route for goods from the Adriatic will be reduced by 185 sea-miles, and from the Mediterranean by 95 sea-miles. The toll for traversing the canal will be only 4·8*d.* per ton for the Mediterranean trade, 9·6*d.* per ton for the Adriatic trade, and 9·6*d.* per passenger; and these tolls have been estimated to attain hardly half the amount which will be saved by shortening the routes. Moreover, the increase in safety, by avoiding the dangers encountered in rounding Cape Matapan, will reduce the rates for insurance. The total tonnage of the vessels rounding Cape Matapan is reckoned at 12,000,000 tons a year, and the Canal Company has estimated at less than half this amount, namely, at about 5,900,000 tons, the traffic which may be relied upon to pass through the canal. The passage of the canal will not be impeded either by the wind or by currents, for it is sheltered on both sides by hills, and the greatest possible difference of water-level in the gulfs at each end would be only 1 foot 8 inches under exceptional conditions. The canal is being excavated in a straight line, in open cutting, having a length of 3 miles 1,656 yards, and it follows exactly the line of Nero's project. It will reach deep water at both ends about 220 to 330 yards from the shore. The bottom width of the canal, of 72 feet, and the depth of 26¼ feet, are the same as on the Suez Canal; but the proposed slopes of 1 in 10 through the rocky portion of the cutting will afford a width at the surface of the water of only 77½ feet, and a cross-section of 2,032 square feet, instead of the width of 177 feet, and the cross-section of 3,272 square feet on the Suez Canal. The small section of the canal will be disadvantageous for navigation, owing to the limited space for the reflux of the water displaced by a vessel in its progress. The approach channels at each end are to have a bottom width of 328 feet, and will be protected by rubble stone jetties. The total excavation in the original design was estimated at 12,865,000 cubic yards, including about 2,400,000 cubic yards for slips or eventual enlargements. The nature of the strata had, however, not been sufficiently investigated, reliance having been placed on the indications furnished by the pits opened by Nero, which did not go down the full depth of the cutting, and from which it was conjectured that the strata were compact enough to stand at slopes of 1 in 10. The region is volcanic, and earthquakes are common; and, consequently, it was not surprising that when the cuttings had reached some depth, a large number of faults were encountered, and a considerable disturbance of the layers of deposit of the tertiary strata was revealed. The maximum depth of cutting to the bottom of the canal is 284¾ feet; and the mean depth, for a length of 2·6 miles, is 190 feet. With this mean depth, the cutting with slopes of 1 to 1 would involve three times the excavation originally anticipated; but fortunately 1 to 1 slopes will not be necessary for the greater portion of the cutting, so that the amount of actual excavation will probably not exceed one and a half times the estimated quantity. Three methods were

devised for excavating the channel: (1) Priestman excavators and dredgers were to remove the alluvial portions adjoining the gulfs on each side, amounting together to 3,270,000 cubic yards in the first year. (2) Special dredgers, constructed for the purpose, were to remove the excavation of the rocky portion, after the rock had been broken up by blasting, to the level of 167½ feet above the bottom of the canal. This excavation, amounting to 7,063,000 cubic yards, was to be effected by the two special dredgers in three years. (3) The cap of the rocky mass above the aforesaid level, comprising 2,616,000 cubic yards, was to be removed by means of dynamite, excavators, and railways. The deep vertical blasting holes did not furnish the expected results, and, therefore, the special dredgers could not fulfil their object; and the only operations which succeeded were the ordinary dredgings at the entrances to the canal, and the excavation of the rocky cap, carried out in the usual way and removed by wagons. The first period of the works, during which the above system of excavation was adopted, extended from the commencement in April 1882 to the close of 1884. The rubble jetties and dredgings for forming harbours at each end were carried out during this period. The harbour in the Gulf of Corinth is protected by two converging jetties, 1,310 feet and 1,640 feet long respectively, with an entrance between their extremities 262 feet in width; and one jetty on the northern side affords adequate protection in the Gulf of Athens. The excavations effected to the end of 1884 amounted to only 1,700,000 cubic yards; and the rate of progress afforded no hope of completing the work in 1888 according to the terms of the concession. The works entered upon a second stage when Mr. Bazaine was appointed Engineer-in-chief; and he extended largely the employment of wagons and locomotives for the removal of the excavations, and made flatter slopes in places to avoid the slips which were threatened owing to the number of faults. The excavation accomplished in the three years 1885–87 reached 6,278,000 cubic yards. At the same time, as the cutting was carried down, the nature of the strata became more manifest; and borings to the bottom of the cuttings, together with a geological survey of the whole route, enabled a definite opinion to be formed of the works required. In December 1886, Mr. Bazaine reported that the principal indispensable works were: the protection of the sides of the canal with masonry in hydraulic lime or cement mortar for a height of 33 feet, along a length of from 2¼ to 2¾ miles, to preserve them from erosion; the formation of a bench, not less than 5 feet wide, on each side of the canal, 6½ feet above sea-level, to enable the walling to be carried out; and the easing of the slopes at certain parts of the cutting to ensure their stability. He estimated that this scheme would involve 2,355,000 cubic yards additional excavation, and an increase of £400,000 in the cost; and he proposed an extension of the time to the end of 1890, and various supplementary works. A commission of experts has prolonged the extension of time for the works to the end of 1891, and the General Assembly of Greece

has granted £600,000 for the additional cost and the supplementary works. The advantages which this canal will afford will have been gained at an estimated cost of £2,400,000, or about £638,000 per mile, with the excavation of 3,509,000 cubic yards per mile, or a cost of 3*s*. 7½*d*. per cubic yard. The Suez Canal, with a length of 92 miles exclusive of the portion through the Bitter Lakes, cost about £20,550,000 for 1,052,500 cubic yards of excavation per mile, which amounts to a cost of £223,000 per mile and 4*s*. 3*d*. per cubic yard. Though the cost per mile of the Panama Canal, about 46½ miles long, cannot at present be determined, the cost of the provisional completion, according to the last estimates of Mr. de Lesseps, would be £65,500,000 for a total excavation of 137,350,000 cubic yards, or 2,947,000 cubic yards per mile, making the cost per mile £1,404,000, and the cost per cubic yard of excavation 9*s*. 6⅓*d*.

L. V. H.

The Defence of Canal-Banks against Damage by Waves and Passing Vessels in the Netherlands.

By the late P. C. VAN KERCKHOFF.

(Tijdschrift van het Koninklijk Instituut van Ingenieurs, 1888–89, p. 1.)

The means employed to prevent the erosion of canal-banks are mostly simple, but in consequence of the long stretches so defended, and particularly since steamer-traffic increases, the total expenses for these works are often very heavy, and their character and construction therefore interesting. Three cases are to be distinguished in choosing the most appropriate system. 1st, Whether it is intended to prevent the undermining and slipping of the bank, when they act as retaining-walls; 2nd, when the banks must be protected against strong currents, and their scouring action; and, 3rd, where the damage by ice or passing steamers is feared. In constructing new canals it will be in most cases advisable to protect the banks and slopes at once, before the water is admitted, and where this is impossible, stone or brick rubble should be sunk, so as not to suspend navigation.

To the Paper are added Tables showing the size of ships allowed to enter some canals in the Netherlands, and the maximum speeds permitted; and also some drawings showing the different modes of construction applied.

H. S.

The Protection of Canal-banks in the Netherlands.

By A. v. Horn.

(Zeitschrift der Architekten und Ingenieur-Vereins, Hannover, 1888, p. 725.)

The extent of the repairs necessary for the proper maintenance of the banks of the principal canals in the Netherlands has much increased of late years owing to the large number of steam-vessels navigating them, and the Paper, illustrated by sectional diagrams, describes the various methods adopted, more especially in the State canals.

The character of the most suitable protective works, for a given position, is influenced by the nature of the soil, the depth of water, the strength of the current, the amount of wash from steam-vessels, and also by the material which can be best utilized for repairs. In Limburg and North Brabant, where the natural soil is of a favourable description, gravel is used for protection, but in Holland the materials are either timber or brick—the latter is the cheaper—but timber must be resorted to where the ground is very soft.

The examples described by the Author vary considerably, one of the simplest being an instance where the natural soil is peat on a substratum of clay or gravel, necessitating the protection of the portion above water only, and effected by wattling, sodding, fascine-work, or a simple form of brick or plank facing. On the Drentschen Canal is an instance of where it is formed by sodding.

Where the protection must extend below the water-line, the method sufficient for ordinary cases is a facing of sheet planking with battens at the back, covering each joint, so as to prevent any soil from being washed out of the bank; but where there is a strong current, as in the case of the Ter Neuzen Canal, the slopes are protected either by a layer of broken brick or stone (occasionally faced with pitching), kept in place by piles and stakes, or, in some cases, by dry stone walling.

As a protection against damage caused by the wash of steamers, a benching planted with reeds is (where they can be made to grow) recommended. The necessary works, under ordinary circumstances, extend from a level of 1 foot 7½ inches to 3 feet 3 inches above, to a depth of 8 inches to 2 feet 4 inches below water-line. When the conditions are unfavourable, such as where the natural soil of the banks is soft, and the wash from steam-vessels considerable, piling may be necessary, or a facing to the slopes of broken stone or pitching.

A description is given of the character and cost per metre of the works upon the principal canals, and in each instance the dimensions of the vessels and the maximum speed permitted, this varying with the draught.

The range of cost is considerable; for the Voorne Canal it is only 7½*d.* per lineal yard; here, however, the protection comprises merely a series of steps or benches of reed sods with a footing of wattles. For more substantial works, as in the North Holland

Canal, the cost is 10*s.* 10½*d.* per lineal yard for a system of piles 4⅝ inches by 4⅜ inches by 12 feet 4 inches long and 2 feet 6 inches apart, supporting a facing of sheet planking 1½ inch thick, and 9 feet deep, with cover battens at the joints.

The work in portions of the Ter Neuzen Canal, where the slope of the bank is 2½ to 1, and the protection below water formed by a top and bottom row of piling 16 feet 5 inches apart with cross rows of stakes in the inclosed space, and filled in with a layer of puddled clay overlaid with three courses of brick on flat, and a top layer of broken stone, the cost is £1 6*s.* 7½*d.* per lineal yard. Above water line the broken stone is replaced by stone pitching.

In the Binnen Aa, the cost in one instance amounts to £2 9*s.* 2*d.* per lineal yard. The protection consists of raking piles 8 inches by 8 inches by 17 feet 3 inches long, 6 feet 7 inches apart, driven at a batter of ½ to 1 with capping piece of 1 foot by 7 inches, supporting a face walling of stone. In this case it was possible to exclude the water from the portion of canal in question while the works were in progress.

The maximum draught of vessels on the various canals ranges from 23 feet 3 inches—in the Walcheren Canal—down to 3 feet 3 inches—in the Munnikezijlsterrijt Canal—and the permissible speed generally for vessels above 9 feet draught is 4·65 miles per hour, except in the Ter Neuzen Canal where it is 5·40 miles per hour, and for those not above 9 feet draught 5·60 miles per hour, except in the Ter Neuzen Canal where it is 6·33 miles per hour, and for those not above 6 feet 6 inches draught 7·44 to 9·30 miles per hour.

D. G.

The Defences of the Seashore and Sand-dunes on the North Coast of the Island of Schouwen. By N. A. M. van der Thoorn.

(Tijdschrift van het Koninklijk Instituut van Ingenieurs, 1888–89, p. 183.)

In the years 1865–1884 some works were executed on the north coast of the island of Schouwen to defend the shore against continual encroachments by the sea. The tides sweep inward from the North Sea, and form deep-water channels close to the land; and to prevent the deep-water and low-water lines being carried further landward, it was decided to construct a number of groynes at distances from each other of 150 metres (164 yards), and at right-angles on the coast-line. These groynes are constructed in the usual manner of fascine layers and stone-covering, pinned down by oaken pegs to the shore. The result was favourable, and the cost of construction comparatively moderate. The maintenance of eighteen to twenty-five groynes between the years 1872 and 1886 amounted in total to 68,442 florins, or £5,703 10*s.*

The Paper is accompanied by a plan showing the situation of the works. H. S.

Landslip in part of the Shore of a Polder in the Island of Noord Beveland. By C. L. M. Lambrechtsen.

(Tijdschrift van het Koninklijk Instituut van Ingenieurs, 1888–89, p. 51.)

In the morning of the 28th of October, 1886, the sea-dyke of the Vlietepolder was found to be seriously damaged by a sinking of the seaward slope into the estuary, over a distance of 300 yards, probably during the preceding low tide. This sea-dam forms part of the northern shore of the island of Noord Beveland. It is subject to continual accidents, the history of which dates back to the years 1530 and 1532, when the whole island was submerged through breaches in the dykes during heavy storms and high tides. Ever since then the endeavour to regain the lost ground has been a continual struggle against the encroaching estuary, of which the deep-water channels seem to have a tendency to change their general course in a more southerly direction, forming deep creeks with steep sides, ever approaching the shores of the island. The cause of these continual changes of the direction of the currents must be sought in the changes in the sandbanks further out to sea, which indicate a tendency of the tidal currents from the English Channel to flow towards the estuary along the shortest way, and ever closer to the northern shores of the island. Borings have shown the soil down to great depths to consist of diluvial loams and sand-beds which are too soft to resist the scour, or to form an obstacle to the influence of the submarine currents.

The construction of groynes for defending the shore from the currents proved of little avail, as the intervening parts continued deepening, and the groynes themselves slid into the holes thus formed. In 1866 the system was changed to a complete covering of the foreshore up to considerable depths with contiguous stone-covered osier-mattresses. Though the occasional slipping of the dyke was not always prevented, the foreshore was thus more effectively protected.

Immediately after the breach in the sea-dam occurred in October, 1886, measures were taken to construct an inner embankment, landwards of the ruined part of the dyke, to prevent the whole polder from being submerged. The mass of soil which had slipped seawards formed a shallow to the eastward, while immediately in front of the breach a deep hole was sounded. The protective covering of the foreshore further out was found unimpaired. On comparing the soundings taken a few months previous to the accident with those obtained after its occurrence, its sudden character was revealed, as previous observations had not indicated danger. The cause of the accident was considered to be that the water contained in the porous subsoil rendered this semi-fluid, and on the sea-level in the estuary falling after a high tide, it flowed seaward, carrying with it large quantities of sand and shells, and in this manner undermined the dyke resting on it.

To the Paper are added plans showing the situation, and the works constructed before and after the accident.

H. S.

New Harbour Works at Bremen.

(Zeitschrift des Vereines deutscher Ingenieure, 1889, p. 97.)

Bremen, now the second port of Germany, is situated on the Weser, 75 miles from the sea, and 38 miles beyond what, until quite recently, was the limit of large sea-going vessels. It is therefore in no way specially adapted by nature to its present commercial position, but has attained to this entirely through the great engineering works undertaken by the enterprise of its inhabitants. The first work was the improvement of the Lower Weser, deepening and enlarging the channel, so that it is available for vessels of 20 feet draught. The work was at first hampered by want of funds, but was afterwards able to progress in a satisfactory manner. The removal of the bar above the previously navigable channel increased the velocity of the current and the volume of water in the proportion of 1 to 2·5. Many tributary streams had to be dealt with, reclamation works carried out, about 31 million cubic yards dredged, and 40 million cubic yards excavated. The cost of this river improvement was as under:

	£.
Land and compensation	24,750
Dredging and excavation	1,182,091
Improvement-works on main channel	137,443
Occupation-works and tributary channels . . .	47,500
General expenses and miscellaneous works . .	108,216
	£1,500,000

The harbour works at Bremen are constructed chiefly on a plot of land long previously acquired by the corporation, and free from all buildings. This land, about 225 acres in extent, is of somewhat irregular shape, about 8,200 feet in length, and with a mean width of 1,300 feet. The end of the land down stream broadens out considerably, and the site was most favourable for connection both with the streets of the town and with the railway sidings, so that it was in every way suitable for the works. The harbour is open, and has at present been constructed with a depth of 22 feet of water, but the quay-walls are of sufficient depth to provide for further dredging to the extent of 3 feet, making 25 feet in all. The harbour is entirely surrounded with quay-walls of brick, with a face batter of 1 in 10; of which walls, 12,300 feet are built on piles, and about 900 feet adjoining the river, on heavy concrete foundations. The quays are paved with stone setts on cement, and are fitted with bollards, mooring rings, vertical and floating fenders, and all the necessary appliances for ships alongside.

The harbour offices comprise board-room, manager's office, and harbour-master's house, with adjacent engine and boiler-house. The main block of warehouses is 492 feet long, and 77 wide, and comprises a basement, three storeys, and attic floor. This block is divided into five sections by cross fire-walls, 98 feet 4 inches long. The working load for the ground floor is taken at 369 lbs. per square foot, for the first and second floors at 307 lbs. per square foot, and for the top floor at 204 lbs. per square foot. The total floor-area is 16,744 square yards. There are also extensive workshops.

Hydraulic power is used for all the machinery, at a working-pressure of 50 atmospheres. There are four pumping-engines, with single plungers of 4·25 inches diameter, and 23·64 inches stroke, and making 60 revolutions per minute. This gives a delivery of about 792 gallons per minute to each accumulator, or an effective total power = 400 HP. Three engines suffice for all general purposes, the fourth being in reserve, but all four can be used simultaneously. The harbour machinery comprises:

Quay.		Warehouse.	
Thirty-one	1½-ton cranes.	Sixteen	1½-ton cranes.
One . .	4 " "	Twenty	1½ " hoists
One . .	10 " "	Twenty	1½ " winches.

The whole of the quays, warehouses, offices and workshops are lighted by electricity, the interiors of the buildings by one thousand seven hundred and twenty glow-lamps, and the quays, &c., by sixty-two arc-lights. The motive power for this installation is derived from two vertical engines of 180 HP. each.

There is a floating-crane or sheers with double gearing for maximum loads of 10 and 40 tons respectively, with water-ballast counter-balance. The pontoon is 95 feet 2 inches long, 32 feet 9 inches wide, and 8 feet 4 inches deep; the draught of water, under full load, being 5 feet 1 inch. The two fore-legs are 88 feet 6 inches long, and the rear leg 92 feet 6 inches. The crane is worked by steam, which is utilized also for a fire-engine mounted on the pontoon. The deck is constructed to carry loads up to 40 tons.

The repairing-dock is 328 feet long, and 49 feet 3 inches wide, accommodating vessels up to about 2,700 tons burthen.

The cost of the harbour works was allotted as under:

	£.
Land	109,800
Earthwork	133,455
Quay-walls	345,600
Warehouses, workshops, &c.	536,730
New streets	106,500
Railway sidings	87,500
Custom House, &c.	50,000
Sundries	230,415
	£1,600,000

Some of these items were varied by alterations during the progress of the work, but the inclusive cost is unaffected. Of this amount, the works carried out to October last had cost £1,200,000.

P. W. B.

Description of "Tandjong Priok," the Port of Batavia.

(Description de "Tandjong Priok," Port de Batavia. 8vo. Plates. La Haye, 1889.[1])

This port is $4\frac{3}{4}$ miles to the east of the canal which connects Batavia with the sea. It consists of an outer harbour, protected by stone jetties, communicating with an inner harbour, a basin, and a coal harbour. The Batavia canal is connected with the outer harbour by the western canal, and with the inner harbour by the southern canal. These two canals, together with the outer and inner harbours, surround an island, on which the quays, sheds, customs warehouses, the station of the Tandjong Priok and Batavia Railway, sidings, workshops, and other buildings are situated. The land bounding the eastern side of the inner harbour is destined for a coal depot. Outside the outer harbour, the roadstead of Tandjong Priok affords an excellent anchorage. The converging jetties, enclosing the outer harbour, start from the shore at a distance apart of 3,610 feet, and converge gradually till they curve round at right-angles near their extremities, and leave an entrance 525 feet wide between the pier heads, enclosing altogether an area of about 346 acres. A channel has been formed in the harbour, 984 feet wide for 2,300 feet from the entrance, and then widening out to 1,640 feet at the entrance to the inner harbour and basins. The channel has a depth of $24\frac{1}{2}$ feet below the lowest water-level, increasing to 28 feet at the entrance, the average rise of tide being only from 2 to $2\frac{2}{3}$ feet; it is marked by six buoys, and moorings are provided for vessels in the channel, and also beyond the channel on each side, for vessels of small draught. The inner harbour, 558 feet wide at the bottom, has a masonry quay-wall along its western side, 3,280 feet long, and pitched slopes on its southern and eastern sides; and it has a minimum depth of water of $24\frac{1}{2}$ feet. The western and southern canals have a depth of $8\frac{1}{5}$ feet, and a bottom width of 49 feet, like the inland canal to Batavia, $5\frac{2}{3}$ miles long. Various other details relating to the port are also given.

L. V. H.

Works of the Port of Tunis. By G. A. Renel.

(Le Génie Civil, vol. xiii., 1888, p. 370, 3 woodcuts.)

Tunis is situated at the inland end of a large shallow lake, which is connected with the sea by a narrow channel opening on to a fine

[1] The original is in the library of the Inst. C.E.

roadstead, with the town of Goulette on its shore. The direct distance between Tunis and its port is about 5 miles. The passengers for Tunis, and some of the goods, are disembarked at the port, and proceed by rail round the lake, a distance of 13 miles; whilst most of the goods are conveyed in shallow vessels across the lake. Works have been commenced for enabling seagoing vessels, and the regular service of steamers between France and Tunis, to reach the town itself. These works consist of a basin of $29\frac{2}{3}$ acres at Tunis, with a depth of $22\frac{1}{3}$ feet; a canal of the same depth across the lake, with a bottom width of $72\frac{1}{16}$ feet, but enlarged near the centre for a crossing-place, affording communication between Tunis and Goulette; and a channel between rubble-stone jetties, extending from the canal into the sea to a depth of $22\frac{1}{3}$ feet, with a bottom width of 328 feet. The works are to be completed in 1894, at an estimated cost of £480,000.

L. V. H.

High Walls or Dams to Resist the Pressure of Water.

By J. B. Francis, Past President Am. Soc. C.E.

(Transactions of the American Society of Civil Engineers, vol. xix. 1888, p. 147.)

The Paper is a criticism of the methods adopted in designing high masonry dams. The Author objects first that engineers are not justified in applying the results of tests of small cubes in determining the strength of great masses. In large masses, the lateral support is very considerable, in small cubes it is slight. He appeals to some experiments of General Gillmore, which seemed to show that the crushing resistance per unit area increased with the size of the specimens. Next, he appeals to the fact that tunnels can be driven without timbering in clay, as proving that lateral support alters the distribution of stress in great masses, so that the stress on any area cannot be assumed to be simply the weight of material above that area.

A high dam may fail (1) by overturning, (2) by sliding, (3) by crushing of the material. A dam whose section is a right-angled triangle has the greatest resistance to overturning. Supposing that for safety the resultant thrust at the base is to be within the middle third, then the Author deduces that the width of base must be 0·666 of the height. The action of water-pressure under the base is then discussed. The Author assumes a water-pressure under the base equal to the pressure due to the head at the up-stream face, and diminishing to zero at the down-stream toe. Taking this into account the width of base must be 0·89 of the height. As to sliding, the Author concludes there is no danger. As to crushing, the Author points out that on the accepted theory the maximum crushing-stress, with the resultant thrust at one-third the width of base from the down-stream toe, is double the mean pressure due to the weight of masonry. But then

the Author assumes that the ordinary theory is erroneous, and that, instead of the pressure at the base varying uniformly, the maximum being at the down-stream toe, it really varies according to quite another law, the maximum stress being transferred towards the interior of the dam, and the stress vanishing at the down-stream toe. He thinks the maximum stress must be at the point where the resultant thrust cuts the base, and that it will decrease to zero at both up- and down-stream edges, the stress varying as the ordinates of quadrants of ellipses. The toe is thus relieved of excessive pressures by its transfer to parts of the base more capable of supporting them.

The Paper contains some experiments on the distribution of water-pressure in a block of porous cement mortar. These experiments seemed to show that water under pressure will penetrate through the mass of a masonry dam.

W. C. U.

The Osselitz Dam. By Paul Grüber.

(Wochenschrift des österr. Ingenieur und Architekten Vereines, 1888, p. 347.)

This dam was the most important of the works connected with the regulation of the River Gail, and, when completed in 1877, was at first provided with a smooth pavement or apron for the protection of its foundations from the scour of the water passing over, but within a year this was almost entirely destroyed. The crown of the dam was then furnished with a projecting shoot made of timber, so that the water might fall clear of the foot of the work, and a loose rough stone apron was substituted for the rigid pavement. This arrangement answered well for some time, but the timber shoot suffered much in the winter of 1882 and 1883 from the vast accumulations of ice at the foot of the dam, which extended right up to the top, and loosened many of its supports, and on September 27th and 28th, 1885, a disastrous flood occurred, which destroyed the shoot entirely and nearly brought about the destruction of the dam also.

In arranging for the repairs to the body of the dam, it was decided (as in other dams in the Gail valley) to lead the Osselitz stream in a side channel blasted out of the precipitous and rocky bank. This channel was made 12 metres wide, with bed 2½ metres below the existing crown of the dam; the area of the discharge channel is therefore 30 square metres, and the velocity of the stream being about 3·2 metres per second, the new channel will discharge about 100 cubic metres per second.

The repair of the dam was a most difficult and dangerous operation, but was completed without accident, and the foundation may now be considered safe, for since 1886 there have been no material changes in the longitudinal section of the stream, which prior to that time were most remarkable, though confined to a comparatively small distance from the foot of the dam.

The total cost is given as follows:

	Florins
Original cost	13,221·05
Coping on shoot	1,055·13
Repairs to apron	487·45
„ „ dam and formation of side channel	9,555·16
Total	24,319·09

or about £2,030 at present rate of exchange.

The Paper is furnished with diagrams showing cross sections, ground plan and elevation of the dam, longitudinal sections of the river-bed below the dam, showing the effect of scour at different periods, and a contoured plan of the basin enclosed by the dam at different water-levels.

W. H. E.

Well-Lining for Filtering Turbid or Impure Waters.

By Max de Nansouty.

(Le Génie Civil, vol. xiii., 1888, p. 390, 4 woodcuts.)

In searching for a supply of water for Rambouillet, Mr. Legouez felt certain that a considerable amount of water must exist in the thick stratum of Fontainebleau sands lying between the chalk and the boulder clay in that district, fed by the rainfall over the forest of Rambouillet and the adjacent plains. A boring proved the correctness of this view, and that the water resembled, in freshness and purity, the best spring-water, containing just sufficient lime to correct the insipidity of distilled water. But on attempting to pump up the water, the fluidity of the very fine sand proved so great that a supply of water could not be procured under such conditions. After an exhaustive inquiry, due to the desire to utilize, if possible, this excellent water-supply at a depth of only 40 feet, instead of searching for a supply in the chalk, by passing with a water-tight lining through the sands to a depth of 160 feet, the system of a filtering lining, devised by Mr. Lippmann, was resorted to. The lining was in this case octagonal in section, formed of frames in which the porous filtering-plates are fixed; and it is hermetically closed at the bottom. A well is first bored, and lined as usual with sheet-iron, and is carried down into the water-bearing sands till an adequate head is obtained to ensure the requisite supply, depending on the diameter of the filtering lining inserted. The filtering lining is then put down, and terminated towards the top by an adequate length of water-tight pipes, above the level up to which the supply is to be drawn. The lining-pipes are then withdrawn, and the water is free to percolate through the filtering-plates. The lining at Rambouillet had a diameter of 1 foot 10 inches, and the filtering lining had a diameter

of 1 foot $3\frac{3}{4}$ inches, and a length of $11\frac{1}{2}$ feet, affording a filtering surface of about $32\frac{1}{4}$ square feet. The bottom of the lining was at a depth of $39\frac{1}{3}$ feet, and 23 feet below the water-level. Two suction-pumps, discharging together 2,640 gallons of water per hour, working for several days in succession, did not lower the water to the level from which it was drawn, and the water continued remarkably fresh and clear. The rate of flow through the filtering-plates is so gentle that there is no chance of the efficiency of filtration being reduced, either by the choking up of the filter or by the heaping up of sand round it, for the sand outside remains in its normal condition. By employing special filtering-plates, or interposing special materials between a double row of plates, it would be possible to draw wholesome water from contaminated strata; and a similar arrangement at the head of distributing conduits would enable a clear supply to be drawn from reservoirs containing turbid water.

L. V. H.

Recent experience in Sewage-Treatment.

By W. H. Lindley, M. Inst. C E.

(Deutsche Vierteljahrsschrift fur öffentliche Gesundheitspflege, 1889, p. 71.)

The Author, as one of four reporters selected to describe the results latterly obtained in Germany of the various systems of clarifying sewage by precipitation, points out the general conditions which must be taken into consideration in the selection of the method of treatment, and states that, in consultation with his three colleagues, a uniform arrangement of their communications has been adopted, in order to facilitate the comparison of the results in each case. The sewerage system of Frankfort is one of the most complete in Germany. It is not a conglomeration of old sewers adapted to modern requirement, or intercepted by a few main sewers; but a complete net-work of new sewers has been built upon the most improved lines, and is arranged on the combined system to take the whole of the waste liquids and dejections of a population of one hundred and fifty thousand persons, occupying an area of 10 square kilometres. The average daily flow varies from 25,000 to 30,000 cubic metres ($5\frac{1}{2}$ to $6\frac{1}{2}$ million gallons). All the houses are completely drained. Cesspools and sludge-chambers with overflows into the sewers are prohibited. The population is provided with thirty thousand water-closets. The sewers have occupied twenty years in execution, from 1867 to 1887, and, with the exception of those for a small district liable to be flooded, inhabited by about five thousand persons, they may now be said to be complete. Until the tanks were ready, there was a temporary outfall into the Main which served until 1885. The original intention was to treat the sewage by irrigation, but, after several years of discussion, it was resolved in 1881 to have recourse to simple deposition in tanks, without chemical treatment; the Government would, how-

ever, only give its consent to the tank treatment on the condition of the adoption of some chemical system of precipitation.

The plans having been approved by the Government in 1882, the works were put in hand at once, and they have now been upwards of a year in operation. In the first instance, when a mechanical system of purification only was to have been adopted, the tanks were designed in duplicate for each bank of the river, and no machinery of any kind was provided. But when chemical treatment had to be undertaken, it was necessary that the outfall works, with their costly plant, should be united and concentrated at one spot. The choice of a site was an easy matter, as the requisite conditions summed up by the Author were only to be found on the left bank of the stream, and it was in this direction only that it might become possible in the future to make use of the effluent for irrigation purposes. The reasons which led to the construction of covered tanks, and to the avoidance of pumping, are discussed in detail.

The tanks are arranged parallel to the river, and the works will ultimately consist of two sets of six tanks each, or twelve in all. The sewage enters the tanks at their eastern end, and the clarified effluent passes out at the western extremity into a channel discharging into the river. Storm overflows have been provided, which only come into use when the rainfall doubles the average daily flow. The works in their future full extent are designed to deal with a dry-weather flow of 40,000 cubic metres, and a wet-weather flow of 80,000 cubic metres. The whole treatment may be subdivided into four stages. The sewage enters at its normal rate of flow into the sand-intercepting chamber, and the speed is then retarded to $\frac{1}{10}$ of the velocity in the main sewer. In this tank the heavier suspended impurities are deposited, and the water, after passing under scum-boards which retain the floating matters, and through strainers which remove the more bulky matters, passes into the mixing chamber, where the requisite proportions of precipitants are added. It passes next along a conducting-channel into the separate tanks, where the velocity is further reduced to $\frac{1}{100}$ of the original velocity. In the four tanks of the first group at present completed, the capacity has been so calculated that the sewage takes six hours to pass through them. They are 80 metres long, and 2 metres deep at the inlet end, while they gradually slope down to 3 metres deep at the outlet. The total volume contained in each tank is 1,100 cubic metres; the velocity at the inlet is 5 millimetres per second, and at the outlet end 3 millimetres per second, or a mean speed of flow through the tanks of 4 millimetres per second. As a rule, all the four tanks are in work at once, but the inlet channels are so furnished with sluices that any one tank at will may be stopped off for the purpose of emptying out the sludge. To effect this, the supernatant water can be drawn off at three different levels, and the sludge may then be pumped out. Each tank is cleaned out once in eight days, so that every second day one of the tanks is emptied—

a process which occupies about five hours. The sludge is of so liquid a consistency that the fall of 1 metre in the length of the tank suffices to convey it by gravitation to the suction-pipes of the pumps at the deeper end. The entire aggregate power of the pumps and mixing machinery is 40 HP.

The precipitants employed are lime and sulphate of alumina; the latter, procured from Duisburg, contains 14 per cent. of pure alumina. The chemicals are proportioned to the volume and the amount of impurities present in the sewage. The volume is ascertained by self-indicating arrangements of a float; the impurities by a scale of eight separate degrees above a fixed standard. The average amount of precipitants made use of is 1 ton of sulphate of alumina to 6,000 cubic metres of sewage-water, and the proportion of lime added is to the alumina sulphate as 1 to 4.

Numerous experiments have been conducted to test the relative values of the lime and the alumina, and the efficiency of precipitation as contrasted with simple deposition in tanks; and Tables too long for abstract, accompanied by graphic representations of the results, are given. Five sets of experiments have been carried out with chemicals—three with lime and sulphate of alumina, and two with lime; and one set without chemicals. The analyses have been made by Dr. Lepsius, and the bacteriological investigations were conducted by Dr. Libbertz.

The chemical results show the vast improvement in the quality of the effluent due to the entire removal of the suspended impurities, and by the use of the alumina, of 40 per cent. of the organic matters in solution.

As respects the bacteriological tests, Dr. Libbertz reports that, where the average number of germs capable of development in the cubic centimetre of raw sewage was three millions (as compared with from four to five million germs usually present in the sewage-water of other large towns), the effluent water, after the sulphate of alumina treatment, contained but, in round figures, 380,000 germs per cubic centimetre; after the lime treatment, 17,500 germs; but after simple deposition, 3,350,000 germs per cubic centimetre.

The Author sums up the advantages and disadvantages of the various precipitants used, and states that the use of lime was found to increase the bulk of the sludge three and a-half times beyond that obtained by the alumina treatment.

The total costs have been as follow:—

	Marks.		£
For land about	200,000	=	10,000
For works: tanks with inlet and outlet channels	435,572	=	21,775
Engine and pumping station	73,795	=	3,689
Machinery	28,818	=	1,441
Plant	6,599	=	330
Siphon under Main	76,530	=	3,826
Office and other expenses	47,582	=	2,379
Total	668,836	=	33,440

The annual cost of treatment amounts to 150,000 marks (£7,500), or 94 pfennige, say 1 mark (1s.), per head of the population, or 1¼ pfennige per cubic metre of sewage-water.

G. R. R.

The Drainage of Wiesbaden. By — Winter.

(Deutsche Vierteljahrsschrift für offentliche Gesundheitspflege, 1889, p. 87.)

The town has grown round four small water-courses which flow together at various points within the boundaries, receive the discharge of the hot springs, and reach the Rhine, some 5 kilometres distant, by means of the River Salzbach. When, as the town increased in size, the sewage discharged into the water-courses became offensive, their channels were culverted, and it was then deemed possible to convey more sewage into them than before, and moreover, drains were constructed to carry away the sewage, which opened direct into those water-courses, and gave rise to considerable pollution of the Salzbach. Various attempts were made to remedy these evils, by the enactment of stringent regulations which prohibited the discharge of fæcal matters, paper, &c., into the sewers, but the by-laws did not suffice to prevent the increasing pollution of the river.

The difficulties caused by the sewage matters in the river were intensified by the presence of no less than seven mills in the short course of 4½ kilometres between the town and the Rhine. For the purpose of these mills the natural flow of the stream was greatly retarded, and whereas the fall would have sufficed to take the sewage away in from one to one and a-quarter hour, the pounding up of the water for the mill-dams caused the minimum time to be extended to about six and a-half hours. Another matter which aggravated the evil was the high temperature of the stream, caused by the hot springs and the retention of the solids in the broad and deep mill-dams. Owing to the complaints of the mill-owners and of the authorities of the town of Biebrich, it became necessary to abate the nuisance, and it was at first proposed to construct an outfall direct into the Rhine, which at the point selected had a low-water flow equivalent to one million times the volume of the fæcal matters, and ten thousand times the total volume of the sewer-water, but permission to discharge raw sewage into the Rhine was refused by the sanitary authorities. The condition of the town rendered any return to a dry-carriage system out of the question, as the use of water-closets had become general, and 28 kilometres, out of a total projected length of 37 kilometres of sewers, had been constructed; and in 1882 Mr. Baumeister had reported very strongly in favour of water-carriage. Finally, in 1885, a tank-treatment was resolved upon, and in order to obtain the requisite motive-power, it was decided to purchase one of the

mills on the Salzbach, situated about midway between Wiesbaden and Biebrich. The mill was of about 7 HP., and the buildings were sufficient for the preparation of the chemicals, and for the pumps, &c.; while the lands attached to it, about 8 hectares in area, could be employed for the tanks and for the reception of the sludge, though the position of the water-wheel and the buildings was somewhat unfortunate, viewed in connection with the latter use of the land.

The tanks are three in number, each 30 metres in length by 10 metres in width, and 2·30 metres in average depth. The principle of downward settling tanks was selected, because of the success of this system in England, though for many reasons the passage upwards and downwards of the sewage appeared to possess advantages; moreover, favourable results had been obtained at Dortmund by the Röckner-Rothe process, based on this mode of treatment. Steps were therefore taken to render the ultimate adoption of this system possible. For this purpose rectangular chambers were provided, through which the sewage must pass upwards and downwards before reaching the tanks. The section to be traversed by the sewer-water in every compartment is 10 metres × 2 metres = 20 square metres. The volume of the dry-weather sewage flow is 7,500 cubic metres in twenty-four hours, and the storm overflows are so adjusted that, in times of the heaviest rain, not more than double this volume can reach the tanks, or 15,000 cubic metres in twenty-four hours = 173 litres per second. If it is assumed that this maximum volume is dealt with in two tanks, with a sectional area of 40 square metres, it gives a mean velocity of 4·3 millimetres per second; or in dry weather, 2·2 millimetres; but even if the tank-space is not fully utilized, the speed could scarcely exceed 3·5 millimetres per second. The tank-space is sufficient to hold the entire sewage for about six hours, or during rainfall for three hours. It was not deemed necessary to cover in the tanks. It is intended hereafter to construct a sand-interception tank, to catch the silt and detritus. The different sections of the works are enumerated, comprising mixing-apparatus, sludge-pumps, air-pumps, and an electric-lighting plant for one arc- and twenty-five glow-lamps. The total cost was 60,000 marks (£3,000), and the cost of the mill and land was 140,000 marks (£7,000), the latter purchase including a valuable spring of fresh water. This total expenditure is equal to 3·3 marks per head of the population (3*s.* 4*d.*). The works, though they have been completed and in operation for upwards of two years, have not hitherto been in normal working order, as the sewage is not yet wholly diverted from the Salzbach. The precipitant employed is milk of lime; the average quantity used per diem being 2,400 kilograms of quicklime. A blower has been provided to aerate the effluent water. The sludge does not meet with a ready sale, and it is therefore used to raise the level of low-lying land. The working expenses are:—

For lime	13,000 marks.	
„ wages	11,000 „	
„ repairs, etc.	5,000 „	
„ sundries	4,000 „	
Total	33,000 „	= £1,600.

Or 55 pfennige ($6\frac{1}{2}d.$) per head per annum.

Taking the interest on capital as equivalent to 24 pfennige, the total cost of sewage-works treatment is 79 pfennige (9·5*d.*) per head per annum.

G. R. R.

The Drainage of Essen. By — Wiebe.

(Deutsche Vierteljahrsschrift für öffentliche Gesundheitspflege, 1889, p. 103.)

The town of Essen has increased in size with extraordinary rapidity during the present century; the population, which in 1852 amounted to ten thousand four hundred and eighty, is now little short of sixty-eight thousand. The trade in coal and in iron has been developed in equal proportions, and the vast works of Krupp alone employ about eleven thousand hands. Various measures have been undertaken to ameliorate the sanitary condition of the town, and among these must be included the drainage-works, which were commenced in 1866, as soon as the water-supply had been completed. The cholera outbreak of that year doubtless gave a great impetus to the development of these works. The sewers receive the surface-water and the rainfall, also the domestic waste-water from the houses, but it has not hitherto been lawful to introduce fæcal matters into the house-drains. The town of Essen is traversed by a small brook which passes through it in a north-westerly direction, and after a flow of 10 kilometres discharges into the River Emscher. This brook, which is mainly fed by the spring-water from the mines, became greatly polluted by the town-sewage, and its condition gave rise to numerous complaints from the residents lower down the stream. After sundry measures had been proposed to remedy the evil, the Government authorities at Düsseldorf accepted a plan involving the construction of tanks to the north of the town, for the clarification of the sewage-water.

Just about this time the firm of Franz, Rothe and Sons were carrying out a series of experiments at Bernburg with the so-called Röckner-Rothe system of sewage-treatment. Details are given by the Author of this process, which has been previously described.[1] After examining the works on this system in operation at Dortmund, it was decided to make an experiment upon a large scale at Essen, and to postpone the formation of tanks. The scheme

[1] Minutes of Proceedings Inst. C.E., vol. lxxix. p 412.

prepared for the whole town involved the erection of four cylinders, 7 metres in height above the water-line, and 4·2 metres in diameter. The sumps were each to be 5·8 metres in diameter and 6·5 metres in depth. It was intended that the water should rise 3 metres high in the sumps; and this, added to the vertical rise in the cylinders, gave a total lift of 10 metres. For the purpose of the experiment, one cylinder and one sump were constructed capable of dealing with one-fourth of the sewage of the town. The total dry-weather sewage-flow (exclusive of the sewage from Messrs. Krupp's works, which is treated separately), is from 10,000 to 11,000 cubic metres. The four cylinders were estimated to have a joint capacity of 18,000 cubic metres; and thus the volume capable of being dealt with per diem in the one actually erected was 4,500 cubic metres. After experiments extending over ten months in the course of 1885–86, which were considered to be favourable, it was resolved to adopt this process for the whole of the town, and works involving an outlay of 250,000 marks (£12,500) were agreed upon in 1886. These works were completed in September, 1887, and have been in operation ever since. In order to convey the water into the works, a weir has been constructed across the Berne, at such a height that 18,000 cubic metres per diem, or 210 litres per second, of the foul water flow into the culvert, which is 2·2 metres in breadth and 1·1 metre in height. The culvert, which is provided with a strainer to keep back corks and the larger floating impurities, conducts the water into the first tank, out of which it passes, by a species of dip-trap, to channels which convey it to the mixing chambers, where the requisite chemicals are introduced. It then enters the four sumps connected with the siphon cylinders.

Very complete details are given of the mode of treatment, and of the self-acting regulator for the proportionate addition of chemicals. The buildings comprise a house for the manager, and dwellings for four workpeople. The horizontal engine is of 20 HP., though at present only 8 HP. are employed. The composition of the precipitants is a secret, but the main ingredient is white lime. At the instance of Professor Koch, of Berlin, many experiments have been conducted in order to ascertain the smallest quantity of lime which must be added to destroy the numerous colonies of bacteria present in the sewage-water. The repeated tests of Dr. Kayser, of Essen, have shown that, with 0·17 kilogram of lime per cubic metre, there remained but 1,260 colonies per cubic centimetre in the effluent, which all belonged to one species, and that it was not until three days had expired that, in consequence of their slow growth, it became possible to detect their presence. The untreated water contained 2,909,300 colonies per cubic centimetre. Tables are given of the volumes of sewage to be dealt with in each month, with an average of 12,000 cubic metres daily. This would involve a velocity of 2½ millimetres per second for the volume of water passing up each cylinder. If the volume rises to 18,000 cubic metres, the velocity becomes 4 millimetres, and the

total period under treatment would be forty minutes. The Author states that he believes that the exhaustion of the air in the cylinder promotes the rapidity of the clarification.

Complete analyses of the sewage-water and of the effluent are given, showing a marked decrease of matters in suspension, and an increased quantity of matters in solution. This latter fact is due to the decomposition of the organic matters in suspension by the caustic lime. The bulk of the sludge is very considerable; details are given of its composition, and of the quantities deposited at various seasons.

Tables are appended of the cost of treatment for each month; the daily expenses vary from 61·29 marks to 83·49 marks, and the cost per cubic metre from 0·39 pfennig to 1·0 pfennig. The expenses for nine months' work were 19,947 marks; say for twelve months, with allowance for cleaning out the sludge-chamber, 27,000 marks (£1,350). Taking the cost of the works and the interest on capital, and adding the annual expenses of treatment, the total expenditure is 42,058 marks; or 62 pfennige (7·5*d.*) per head per annum.

G. R. R.

The Drainage of Halle. By — Lohausen.

(Deutsche Vierteljahrsschrift für offentliche Gesundheitspflege, 1889, p. 123.)

The present population of Halle is ninety thousand, exclusive of the suburb of Giebichenstein, which contains fifteen thousand inhabitants. The town is situated on the right (east) bank of the Saale, and possesses a complete system of sewerage, emptying by gravitation into the river. The old sewers traverse the northern portion of the town, and this district is not included in the present memoir. The Author was instructed in 1866 to prepare a plan for sewering the south of the town, and to devise a system of treatment for the daily flow of 3,000 cubic metres of sewage-water. The volume at the present time, however, does not exceed 900 cubic metres, as the area is not completely built over. The population of this district is about ten thousand. The liquid to be dealt with is the domestic waste-water and the liquid dejections only of the inhabitants, as the solid fæcal matters may not be passed into the sewers, though this regulation cannot be so enforced as wholly to exclude the excreta. The sewage also includes the waste-water from six factories, and the entire rainfall. The water enters the works by two channels, one of which can be closed with a sluice when the volume is small. These channels discharge into a sump, which retains the grosser suspended impurities. The water then flows into four measuring-boxes, mounted on a rotary axis, and as each box fills it descends and causes a movement through 90°, which brings a second measure into action. The chemicals consist of a mixture of sulphate of alumina and silica, prepared by the firm of

Müller and Nahnsen, and a regulated quantity is added to the sewage, which is subsequently treated with lime. In consequence of fluctuations in the strength of the sewage, as well as in the volume, it is necessary to make a further allowance, which cannot at present be so arranged as to be automatic in action. The water is next passed through screens to remove solid matters which would be liable to clog the pumps. After passing the screens, the liquid enters the wells, or sumps, at the bottom, and rises to the surface of the first, whence it is taken by a pipe to the bottom of a second sump, through which also it ascends, and then passes by a closed culvert into the river. Provision is made, by means of a storm-overflow, to exclude all excess in volume beyond the 3,000 cubic metres of sewage for which the works are arranged. The works are situated in a densely populated neighbourhood, and the stench from the sludge at first caused many complaints, and steps had to be taken to collect the foul-smelling gases, and to pass them through a furnace in order to consume them; and this proved entirely successful. A second difficulty was caused by the high price of the chemicals supplied by the firm of Müller and Nahnsen, and attempts have been made to discover some cheaper precipitants, hitherto without result.

Very numerous reports on the working of the process have been issued, and these are so satisfactory that it is proposed shortly to permit of the discharge of the excreta from this district into the sewers. From the bacteriological experiments of Dr. Zopf it would appear that, whereas the raw sewage contained, on the average, twelve millions of germs per cubic centimetre, the effluent, after the chemical and mechanical treatment, yielded but thirty thousand fertile germs, or 4 per cent. only of the former contents in bacteria. The price charged for the precipitants was 20 marks per 100 kilograms, and attempts were made to dispense entirely with chemicals; but it was then found that the resultant sludge could not be pressed into cakes. Lime was then used, and it was ascertained that four times the quantity of lime was needed to produce the effect of the chemicals supplied by the patentees, and the effluent rapidly putrefied. Finally abortive efforts were made to treat the sewage with peat. The sludge, pressed into convenient cakes, is taken away by the farmers in the vicinity; at first they willingly paid a small sum for it, but subsequently they would only have it as a gift. The works cost 35,000 marks (£1,750). The total working expenses per diem, for labour, chemicals, &c., amount to 18 marks (18*s.*), or say 6,570 marks per annum; which, for a population of ten thousand, is equivalent to a cost of 66 pfennige (8*d.*) per head per annum. Taking the interest on the works and plant at 5 per cent., it would entail an addition of 17 pfennige per head, or a total annual charge of 83 pfennige (10*d.*) per head.

The Author states that it will shortly be necessary to deal with the six existing outfalls; to collect the water by means of an intercepting sewer, and to convey it under the Saale by an inverted

siphon to a point outside the town for further treatment. He anticipates that the cost of dealing with the sewage of one hundred thousand inhabitants, at a central station, will not exceed 75 pfennige (9*d.*) per head.

G. R. R.

Disinfecting-Apparatus. By A. Koch.

(Bulletin de la Société Industrielle de Mulhouse, 1888, p. 585.)

Mr. Koch analyses all the phases through which disinfecting-apparatus had passed before a really effective apparatus was matured. Chlorine, creosote, sulphuric acid, and several other chemical products were used as vapours, or in solution or otherwise. It may be judged that, after such treatment, eider-down, mattresses, and articles of linen or silk, had better have been burned. Dry heat was first used in England, then in France and Germany, by which the objects under treatment were subjected to a temperature of about 212° Fahrenheit. But the temperature in the interior of a mattress never exceeded 175° Fahrenheit, while the exterior was scorched. Mr. Koch improved upon this treatment by combining the action of dry heat, by which the air contained in the objects is rarefied, with the subsequent introduction of steam, under pressure, which, without becoming condensed, thoroughly penetrates the articles in a few minutes. These, when withdrawn, are not at all altered, and, after some minutes of exposure to the air, they regain their ordinary appearance. No organism can come out alive. To obviate all danger, the heated air which escapes from the apparatus is caused to traverse a vessel containing boiling water, and is thus purged of all infectious particles which would otherwise escape into the atmosphere. This precaution is very important.

The operation lasts forty minutes; for twenty minutes the objects are submitted to a dry heat, and for another twenty minutes to the action of steam. With an apparatus capable of holding six mattresses and some blankets, one hundred beds may be disinfected in twenty-four hours.

According to a Paper written by Dr. Henri Weisgerber, in 1886, Mr. Koch has adopted the most convenient form of apparatus for rapid action and easy installation. It consists of a cubical chamber formed with a double case of iron and steel, enclosing a stratum of slag-wool, an excellent non-conductor, 5 inches in thickness. The chamber is about 5 feet wide, 8 feet high, and 7 feet 8 inches long inside. It is fitted with a door at each end, and a line of rails on which the articles may be run in and run out on trucks. The available clear space for articles is about 140 cubic feet. At each side of the chamber is located a pile of cast-iron warming-pipes. about $3\frac{3}{4}$ inches in diameter, formed with numerous wing-flanges for the rapid dispersion of heat by radiation and conduction, developing together 300 square feet of heating surface.

Steam of atmospheric pressure is admitted into the heating-pipes. When the doors are closed, the air of the chamber is dilated and seeks to escape, and passes out through the floor by a pipe leading to a vessel containing boiling water, which is heated by steam from the boiler, and by the condensation-water from the warming-pipes. The air can only escape from the chamber by balancing the column of boiling water plus the resistance in the pipes, equal to a pressure of about 3 lbs. per square inch. The air contained in the objects being thus rarefied, steam is injected into the chamber through a pipe pierced with holes, and penetrates the objects with the greatest facility, the temperature of the articles besides being sufficient to prevent condensation. The heat of the warming steam-pipes, besides, aids in evaporating water that may pass as priming with the steam into the chamber. Dry steam is thus ensured in the chamber,—a condition favourable for shortening the operation. In a short time the air is entirely expelled, and its place is taken by steam, which is much more efficacious than a mixture of air and steam. The vessel of boiling water serves at once the purpose of washing the escaping gases, as a regulator of pressure, and as a safety-valve.

When the operation is ended, the steam from the boiler is shut off, and the steam under pressure in the chamber is allowed to escape into the chimney, after which the door is half opened for five minutes before the truck and its load are withdrawn. During this interval the heating-pipes are useful in drying the objects. The results of several special trials are given in the Paper.

The cubical form of chamber has been superseded by the cylindrical form, which is better adapted for resisting even the comparatively slight internal pressure, besides admitting of the application of a higher pressure and temperature for more rapid penetration. It is capable of resisting 2 atmospheres of pressure. An apparatus of this class is in operation in the new washhouses of the hospitals of Strasburg, 4¼ feet in diameter inside, 7¼ feet long, having a capacity of 102 cubic feet. The truck, of galvanized iron, can hold four mattresses and eight blankets. The complete operation lasts less than one hour. A steam-boiler, of 65 square feet of heating surface, is amply sufficient for the supply of steam.

The Paper is fully illustrated.

D. K. C.

Joint for Water- and Gas-Mains. By — PAULUS.

(Dingler's Polytechnic Journal, vol. cclxxi., 1889, p. 346.)

It is well known that serious losses have occurred from the failure of the joints in water- and gas-mains, often, with the latter, leading to fatal results. With the particular kind of joint which forms the subject of the above article, the inventor claims to have eliminated the chief causes of failure which exist in most of the ordinary kinds of joint in use.

Pipe-joints should fulfil the following conditions:—

1. The joint must be simple, easy to make, and should not be unduly dependent on accuracy of workmanship.

2. The pipes must be free to expand and contract without injury to the jointing material.

3. Any alteration in level of the pipes caused by uneven settlement of the ground should not interfere with the tightness of the joint.

4. The jointing material should be cheap, and the lengths of pipe should not require to be of any special or expensive form.

The joint in question was brought out by the inventor in the year 1859, for use on the water-mains belonging to the South Austrian Railways. The lengths of pipe are quite plain without sockets or flanges, and the joints are made with tarred hemp in the following manner.

The ends of two lengths of pipe are placed with about $\frac{1}{16}$-inch space between them to allow for expansion, and are encircled by a hollow collar or sleeve; the section of this collar is of a B shape, forming two semi-circular annular chambers round the pipe, side by side (the flat side of the B lying next the circumference of the pipe); a small hole is drilled near the end of each length of pipe, and in this the tarred hemp is fastened, one rope in each hole; the free ends of the ropes are led out through holes in the collar; the collar is turned round by means of a key which catches in projections formed for this purpose on the outside of the collar; the ropes are thus wound tightly round the pipes until the spaces of the collar are completely filled up, forming a tight yet elastic joint; the inside diameter of the collar is about $\frac{1}{8}$ inch larger than the outside diameter of the pipe, excepting at the annular chambers, where space is left for the hemp rope. The weight of a pipe 6 feet 6 inches long, and $3\frac{1}{8}$ inches bore, is given as 91 lbs., the weight of the collar $5\frac{1}{2}$ lbs., and the weight of a 7 feet 10 inches length of a $6\frac{1}{4}$-inch pipe is 238 lbs., the collar $19\frac{1}{2}$ lbs. A long $17\frac{3}{4}$ inches main with these joints has been in use for conveying water at the Iron Works at Ars, on the Moselle, with very good results. Other examples are cited, and the result of one experiment that was tried with this joint is given, the pressure being 10 atmospheres. The article is illustrated by a woodcut, showing a section of the joint.

H. H. P. P.

The Solution of Municipal Rapid Transit. By F. J. Sprague.

(Transactions of the American Institute of Electrical Engineers, 1888, p. 352.)

In the city of New York the total passenger traffic has increased at the rate of 140 per cent. in each period of ten years since 1866, and is now over 325,000,000 passengers. This enormous rate of increase shows the necessity of carefully considering the cost of passenger traffic in town. The cost of working horse-car roads

includes on an average an item of 40 per cent. for horse motive power, and the cost of a horse suitable for the work may be taken at £35, and his yearly keep and attention at £42.

Taking five of the largest roads in Massachusetts, the West End Road of Boston and the Fourth Avenue line in New York, the average mileage per horse is 10 to 12 miles.

The cost of horse-motive power in America averages about 18*s.* 8*d.* per day on runs of 45 or 50 miles, equivalent to nearly 4½*d.* per car mile, counting only the horses actually on the road, which form 90 per cent. of the stable. In New York the cost per car mile is 5·6*d.* for horses.

Cable tramways have been successfully introduced to reduce the cost of running. The motive power costs 50 to 70 per cent. that of horse-motive power, or as an average, say 3*d.* per car mile. The cost of the track, however, is very heavy, the conduit costing £11,800 to £19,000 per mile. Only 20 or 25 per cent. of the actual engine power is used in moving the cars, the balance being used to move the cable. Large reserves of power must be kept, as failures stop the whole line. The system possesses all the disadvantages of any single centered rigid system of distributing power. In comparison with these systems, and as an example of a modern electric car road, may be noted that of the city of Richmond. The total length of track is 12 miles, 9 miles in paved streets; but the extensions are in unpaved roads, in some cases in clay soil, which in wet weather covers the streets. Curves are as sharp as 27, 30, and 50 feet radius, some on 8 per cent. grades. The grades vary, but are as steep as 10 per cent. The cars have a wheel-gauge of 4 feet 8½ inches, and a wheel-base of 6 feet. Experience has shown the advisability of two guard-rails on sharp curves, which are greased in dry weather. Easy drop switches or preferably tongue switches are used. Power is generated by three return-flue boilers of 125 HP. each. The water is heated to 200° Fahrenheit by a feed-heater. The pressure is regulated within 2 lbs. by an automatic damper. The coal used only costs 8*s.* per ton delivered. The engines are three Armington-Sims developing 125 HP. each, at 250 revolutions, each driving two Edison dynamos of 40,000 watts at 500 volts. The dynamos run in parallel on to two omnibus bars. The circuit outside consists of the overhead and underground. That overhead is composed of a copper wire $\frac{1}{16}$-inch diameter as a main conductor, supplied at distant points by feeders, and carried on poles every 125 feet; the poles are 30 feet long, let into the ground 5 feet. The actual contact wire for the trolley is a silicium-bronze wire, breaking-strain about 100,000 lbs. per square inch, not more than ¼-inch diameter, and supported 19 feet from the road by suspending wires hung from side to side of the road. The contact is made from below by a trolley wheel carried on a pivoted and balanced pole from the top of the car. The rails form the ground circuit, each section being connected to a ground wire, and at intervals of 500 feet to an earth plate. Each car carries two motors, hung

from the axles, with a flexible reactive support on the car-frame. The ratio of gearing between armature and axles is 12 to 1. They are each of 7½ HP. capable of working to 30 HP., and with 50 per cent. efficiency, their tractive effort is 3,000 lbs. They run with fixed brushes both forward and backward.

The grip of the wheels is materially increased by the passage of the current through the wheels and rails. Cars having a total weight of 15,000 lbs. can be worked on a 10 per cent. grade, with a curve 27-foot radius, without the use of sand.

The following are the totals of the working expenses on the Richmond Electric Road:—

WORKING-EXPENSES for THIRTY CARS on DOUBLE-TRACK ROAD.

	£	s.	d.
Fuel	4	2	0
Labour and superintendence	5	0	0
Depreciation, lighting, and repairs	1	10	0
Total expenses	10	12	0

Or about 7*s.* 2*d.* per car per day, running 80 miles equal to 1·07*d.* per car mile.

The road expenses, including inspectors, cleaners, &c., and depreciation on the line amount to 9*s.* 4*d.* per car per day, or 1·4*d.* per mile. The total working expense is 2·47*d.* per car mile, which is less than 40 per cent. of the cost of working by horse traction.

LL. B. A.

Aërial Transport by Wire Ropes. By A. HAUET.

(Revue Générale des Chemins de fer, October 1888, p. 227.)

It frequently happens, in the course of railway construction, more particularly for the working of quarries, the construction of drains, and the removal of earth slips, for instance, that a simple mode of aërial transport becomes a desideratum. At the chalk-pits near Paris, and elsewhere, a simple means of aërial transport has been in use for twenty years, where the distance for the chalk to be conveyed is from 500 to 820 feet in length. Two parallel carrier wire-ropes, ¾ inch in diameter, act as rails, one for ascent, and one for descent. They are fastened at one end to a tree, or a pile, or an anchorage; and they are placed under tension at the other ends, by the aid of a large T-head bolt, passed through a block of timber held by an anchor carriage of wrought-iron plate and angle-iron, loaded with heavy materials. The load is suspended from each carrier-cable by means of a triangular frame embracing two 8-inch grooved pulleys which run on the rope, and a suspension-hook. This apparatus is connected by a short piece of chain to an endless wire rope, from ⅜-inch to ½-inch in diameter, according to its construction, running on a grooved pulley, 4 feet in diameter, at each end of the course.

The loads, earth and materials, are carried in buckets of from $3\frac{1}{2}$ to 5 cubic feet in capacity. The loaded buckets descend by gravitation, drawing with them the endless rope, which draws up the empty buckets. The motion is arrested when the buckets arrive at their destination by a friction wood block; or, if the incline exceeds 15 per cent., by a steel brake. Inclines of from 30 to 40 per cent. can be worked.

D. K. C.

Steep Wire-Rope Railway at Montreux, Switzerland.

(Die Drahtseilbahn Territet-Montreux-Glion, von Emil Strub. Aarau, 1888.[1])

This little railway, which has been working successfully since 1883, has some features of interest.

Above the well known cluster of villages at the east end of the Lake of Geneva, extending from Clarens to Chillon, rises a bluff hill called the Rigi Vaudois, much frequented for the salubrity of its climate and for its splendid views; the little village of Glion, at its summit, is about 1,000 feet above the lake, and is approached by a winding carriage-road, the ascent of which occupies about an hour.

The traffic between Glion and the populous lake shore below had become so considerable, that the possibility of shortening and cheapening the transit was seriously considered. The local authorities consulted Mr. Riggenbach, the engineer of the Rigi Railway, who recommended a direct line to be formed up the slope of the hill with a very steep gradient, and worked on a plan very commonly adopted for steep inclines of short length. A carriage weighted with water, descends, and draws, by a wire rope, another carriage up an adjacent line.

The horizontal length of the railway is nearly 2,000 feet, and the total rise about 1,000 feet, giving a mean gradient of 1 in 2. But the ground did not admit of the gradient being uniform throughout, and the upper part, for more than half the length, had to be laid to an incline of 57 per cent., or a rise of 1 in $1\frac{3}{4}$, the lower portion being proportionately flatter. This is probably the steepest line for general passenger-traffic in existence, except that on the cone of Vesuvius, which is 68 per cent., or about 1 in $1 \cdot 6$.

The gauge is 1 metre. The carriages have only one class, and each will carry twenty-six passengers, with a moderate amount of luggage. The weight, when loaded, is about 9 tons.

The quantity of water necessary to give the motion depends on the loading of the two carriages respectively. The most unfavourable case is when the ascending carriage is full, and is on the steep part of the incline, while the descending one is empty and is on the flattest slope; in this case, about $6\frac{1}{3}$ tons of water are necessary to produce a balance, to which about $\frac{1}{2}$ ton has to be added to overcome the friction. The effective moving power

[1] The original is in the Library of the Inst. C.E.

varies during the journey, partly from the changes of gradient, and partly from the constantly varying gravity of the rope on each side. The effect of this variation is, however, fully commanded by the hand-brakes on the descending carriage.

In introducing a communication of this kind, with such a very steep slope, it was absolutely necessary to adopt such precautions as would thoroughly satisfy the public as to its security. Great care and attention were therefore bestowed on this matter; indeed, the Swiss Government refused to sanction the line for public use until satisfied of its safety. It was well known that the ordinary railway brakes, acting by friction on the rails, would be ineffective to stop the carriage, and some arrangement had to be contrived which could be thoroughly relied on.

For this purpose it was determined to lay down a rack between the rails (although not wanted for propulsion), and to put upon the carriage a cog-wheel gearing into it; this wheel had brake-drums on its axle, and when clip-brakes were applied to these drums they would, acting through the cog-wheel, effectively check the velocity, and if screwed up hard would stop the carriage altogether. But in view of the tremendous consequences at stake, it was not considered sufficient to trust to this. In urgent need the brake machinery might become deranged, or the brakesman might lose his head; and it was to be recollected that if the rope broke, the accident would release, not only the descending carriage to which the brakes were already applied, but also the ascending one, which was quite free; and, moreover, that to be of service, the check must be applied instantly, before the loosened carriage had acquired any great impetus in its downward course.

For these reasons another brake has been added, perfectly independent, and working automatically. In the quiescent condition this brake is kept fully applied by a heavy weight, sufficient to render the carriage immovable. When the carriage starts the weight is lifted off by the tension of the rope; but if the rope should break or lose its hold, the weight automatically resumes its action, and the carriage stops of its own accord. The effect of this has been repeatedly tried, by purposely detaching the rope, when the automatic action is found sufficient to bring up the carriage after only a few yards' descent. This brake may also be worked by hand.

There are thus three independent brakes to each carriage, two hand and one automatic, either of which is sufficient to stop the motion. When the carriage is descending the brakesman stands at its front end, with one of the brake-handles in each hand, and with these he regulates the speed of the descent, keeping it down to about 2 or 3 miles an hour; and if a breakage were to occur the stoppage by these alone would be easy and simple, even not counting the automatic addition. With the ascending carriage the brakesman ought also to be at his post, and always on the alert; but to provide for human imperfections, the automatic action is there, and as the carriage is moving upwards with a little

velocity, there is at any rate more time to act than with the descending vehicle.

The brake arrangements were approved by the Railway Department; the result of five years' experience has shown them to work well; and they have fully satisfied the local authorities of the district.

It cannot be denied that on looking down the incline from its upper end, a sensation almost approaching to giddiness is felt at the steepness of the descent, and some persons who ascend it for the first time experience a nervous fear as they get near the summit; but this soon wears off, and the inhabitants now go up and down daily with as little thought as if they were on a level line.

The speed of travelling is about $1\frac{1}{2}$ metre per second, or 3 miles an hour, the whole journey occupying about eight minutes. The charge is 1 franc for the ascent, 75 centimes for the descent, and $1\frac{1}{2}$ franc for the double journey. The number of passengers in the year 1886 was 84,435.

The capital of the Company is 500,000 francs, in shares and debentures, the outlay having been nearly 470,000 francs. The dividend on the shares for 1886 was 5 per cent., a fund being also put aside for reserve, renewals, and amortisation.

H. Sc.

Adhesion- v. *Rack-Railways.*

(Zeitung des Vereins deutscher Eisenbahnverwaltungen, 18 April, 1888, p. 267.)

The problem to be solved may be expressed as follows:—Up to what gradient can adhesion-locomotives be employed for uninterrupted and safe transport of a given amount of traffic? or, in other words, at what gradient does the usefulness of a rack locomotive begin?

The most important point to be ascertained is the value of the coefficients of adhesion. It is not sufficient to know the maximum to which this value can rise, nor the minimum to which it can fall. The ruling factor is the average or mean value which adhesion attains in ordinary conditions of weather. The experience gained up to the present time on various mountain railways worked by adhesion offers valuable and sufficient data.

The late Mr. Stocker, Locomotive Superintendent of the Gotthard Railway, carried out exhaustive experiments, in order to obtain the most accurate values possible for the coefficients of adhesion upon the following mountain railways:—

1. The Brenner and Puster Valley Railway, ruling gradient 1 in 40, smallest curve-radius, 285 metres (935 feet).

2. On the Apennine Passes: Pistoja-Poretta, gradient 1 in 38·5, with many sharp curves and many tunnels; Pontedecimo-Busalla (Giovi Railway), gradient 1 in 28·5, without tunnels and with easy curves.

3. On the Bussoleno-Modane section of the Mont Cenis Railway, gradient 1 in 33, curves comparatively easy.

The results of these experiments, for which Mr. Stocker used eight-wheel-coupled engines with 51 to 53 tons weight on driving-wheels, were published in the "Eisenbahn," of Zurich, in 1878.

It is there shown that the maximum coefficient obtained for the adhesion was $\frac{1}{6\cdot4}$ during a trip on the southern approach to the Mont Cenis tunnel, on which inclines of 1 in 33 occur. It does not appear advisable, however, to accept this unusually high coefficient as a standard, since it could only be reached under unusually favourable conditions of weather.

On the Tyrolese railways, Mr. Stocker arrived at an almost identical coefficient when using exceptionally good sand—that is to say $\frac{1}{6\cdot5}$; still, for these lines, when the question of train-load was being determined, a maximum coefficient of $\frac{1}{8\cdot3}$ was, according to Kramer, that assumed for the calculations.

In a general way, under normal circumstances and not unfavourable conditions of weather, the coefficient of adhesion may be taken at between $\frac{1}{7}$ and $\frac{1}{8}$; for Stocker found, on the open portion of the Giovi Railway on gradients of 1 in 28·5, that the adhesion was almost invariably equal to $\frac{1}{7}$ of the weight, whilst on the Apennine Pass Pistoja-Poretta, it was in the proportion of 1 to 7·6.

The late Mr. Victor Kramer, Locomotive Engineer of the Austrian Southern Railway at Innsbruck, fully confirms these results in his treatise "On the Locomotive Service of the Brenner Railway." He there speaks of adhesion as a thoroughly capricious factor, which, from a maximum value of $\frac{1}{4}$ in the best season of the year, falls, under special circumstances, to as low as $\frac{1}{15}$. Even leaving out extreme cases, not more than $\frac{1}{5}$ in summer, and, with the help of sand, $\frac{1}{6}$ in the winter, can be reckoned on. Further on he states that the average value of the coefficient of adhesion can, under ordinary circumstances, be taken at $\frac{1}{7}$.

Both these authorities repeatedly, and with conclusive evidence, call attention to the influence which variations in temperature and the state of the weather exercise upon the adhesion, and these are precisely the points which are of peculiar importance since they are intimately connected with the circumstance of the elevated position of a line. For instance, in the case of the Giovi Railway, as soon as the south wind sets in, bringing moisture from the sea, the coefficient of adhesion falls to $\frac{1}{9}$; on the Brenner Railway, a coefficient of $\frac{1}{8}$ is assumed for calculating the train-load for unfavourable conditions of weather, although it really, according to Stocker's observations, very often falls as low as $\frac{1}{9}$ and even $\frac{1}{10}$.

In the tunnels, which it is so difficult to avoid on mountain railways, a great reduction in the adhesion invariably shows itself. This can frequently be observed on the Semmering Railway; cases occur where trains have been appreciably delayed solely in consequence of repeated and continued slipping of the driving-

wheels. In the Mont Cenis tunnel, with a ruling gradient of 1 in 43, the coefficient of adhesion seldom exceeds $\frac{1}{8.5}$, and is generally considerably less.

The foregoing observations tend to show that a locomotive—supposing its total weight to be utilized for adhesion—can, even under favourable conditions of weather, only move 1·3 time its own weight up a gradient of 1 in 20, or, on a gradient of 1 in 16·6, only the equivalent of its own weight; and, therefore, an eight-wheeled-coupled engine of 50·5 tons load on driving-wheels can only, on an incline of 1 in 16·6, transport a useful load of 23·5 tons besides its tender of 27 tons. Each engine on the Hartz line, from Blankenburg to Tanne, weighs 57 tons, and, by help of the rack-rail, transports a train-load of 122 tons at 6·2 miles speed up an incline of 1 in 16·6; had the same train to be worked by adhesion locomotives, two tank-engines, each with 61 tons load on the driving-wheels, would be necessary. A regular traffic with such train-loads could not, however, be depended on, owing to the great variations in the adhesion.

The employment of the rack-rail affords just this important advantage, that a given amount of traffic can be satisfactorily maintained under all circumstances with perfect regularity, even on gradients where the variations in the adhesion would show themselves in a most injurious manner, and prove a source of great inconvenience and even danger.

It is true that there are railways worked by adhesion alone, where inclines of 1 in 16·6 and even 1 in 12·5 occur; in most cases they are, however, only tourist railways, having to deal with a comparatively light traffic, and this only during the most favourable time of year. Nevertheless, it appears that the use of adhesion alone on such venturesome inclines is permissible only in exceptional cases. The Author witnessed a case on the Uetliberg Railway, where, on a rather foggy day, the locomotive could scarcely move its extremely light train on a gradient of 1 in 12·5 in consequence of slipping of the driving-wheels.

When instances are quoted of adhesion engines, of say 45 tons weight, moving a dead load of 100 tons on gradients of 1 in 16·6, it is not necessarily a matter for doubt, since during the construction of the Mont Cenis Railway on the temporary line built on the Fell system, with inclines of even 1 in 12, trains were run without using the centre rail. But such instances are only exceptions which may occur with more or less frequency.

The coefficient of adhesion has also, however, a most important part to play for the descent of an incline, as regards the safety of the traffic; and here, in the choice of gradients, the assumption of too high a coefficient may involve a constant danger. On the Semmering Railway, a case occurred where a descending goods train—in which the auxiliary engine, previously employed to push the train up a bank, was now coupled in front of the engine—could not be controlled on a gradient of 1 in 40, or, in other words, fairly ran away, because the speed on passing from the horizontal

to the 1 in 40 decline had probably not been checked soon enough. The train could only be brought up on a gradient of 1 in 100; and, as all the brakes were duly applied, it is probable that the case would not have occurred if the adhesion had been sufficiently great.

A similar incident on the Brenner Railway is mentioned by Stocker in the Paper before referred to:—"An ordinarily heavy train with two engines, which left Franzensfest at night in bad weather, had lost time on the ascent, and exceeded all prescribed limits of speed between stations in descending the Brenner. In spite of the constant whistling by the drivers owing to the increasing speed of the train, the wagon-brakes only worked on each occasion just before the station was reached."

During the trip, Stocker several times remarked the speed to be increasing, although both the tender engines had their full brake-power exerted all the time, and he considered the coefficient of adhesion on this occasion to have been not more than $\frac{1}{7}$.

Kramer expresses himself as follows with reference to the descent of gradients.—"Downhill it is always the question of safety which is of primary importance, and half measures must not be thought of. Here again, that capricious element, the adhesion, plays the chief part, whether considered as traction-power or brake-power. There are cases, and especially in places lying at great elevations above sea-level, where the coefficient of friction certainly does not exceed $\frac{1}{15}$, and is possibly even less than that value, as for instance, when sleet is falling and the temperature is almost at freezing-point. Here sand alone can more or less help. Even supposing that it is tolerably effective as regards the engine brake-power, still the other brakes get but little benefit from it, as the sand layer on the rails is soon rubbed or washed off."

The employment of sand affords, it is true, an excellent means of increasing the adhesion, since the grains of sand, by their being driven into the surface of rail and wheel, constitute, as Stocker most correctly remarks, no less than a very imperfect rack and pinion, so that on mountain railways where the use of sand is customary, the principle of pure adhesion is, properly speaking, already broken through. Even then, sand cannot be depended upon under all circumstances, and must, when a really good result is desired, be of the very best quality.

Experience on the Semmering and Brenner railways shows that on inclines of 1 in 40, the driving-wheels slip to such an extent, in spite of sand, and especially in the damp tunnels, that the trains almost come to a standstill.

Washing the rails by means of a jet of water has proved more advantageous than even sanding; Stocker calculates, upon the basis of experiments made in the Hauenstein tunnel on the Olten-Laufelfingen line, that the coefficient of adhesion which can with certainty be attained by the use of a water-jet, is $\frac{1}{6\cdot8}$; whilst he observes that it is highly probable that it is even higher.

By the gearing of the pinions into the rack, a much more powerful result must necessarily be produced than by the use of sand or

water; the efficiency of the locomotive for the ascent of a gradient, and the safety of the traffic for the descent will be much greater than on an adhesion line for similar inclines.

When, therefore, with given ascending or descending gradients a definite performance is demanded, that system would be made use of with which that performance could be carried out with safety, even under specially unfavourable conditions, as, for instance, in bad weather.

According to the experiences already cited, the opinion most decidedly expressed by Mr. Kramer in the before-mentioned Paper, on the subject of adhesion-locomotives, can only be agreed with when he declares as follows:—

"It seems, therefore, in every way appropriate that the German Railway Union has agreed to fix 1 in 40 as the limit of steepness of gradients which is not to be exceeded; since beyond that limit the working of a line by locomotives becomes less and less justifiable."

As soon, therefore, as this fact has been acknowledged which has been proved in practice, or, in other words, as soon as the conviction has been arrived at, that, if the traffic is to be regular, safe and economical, an adhesion-railway may not be constructed with such daring gradients as a rack-railway, then it will be seen that a line of the latter type must form beyond dispute the shortest route by which to connect any two given points at considerable elevations above the sea.

This shortening of the route, which is frequently considerable, has the further result of rendering unnecessary various expensive works when laying out the line, thus reducing the cost of construction, to say nothing of the time gained and the diminished interest payable on the building capital, all the traffic expenses being also reduced. Had the Semmering Railway, for instance, been led straight away from Gloggnitz through the Schottwien Valley and a rack railway with gradients of, say, 1 in 20 employed, the line would have been 15 kilometres shorter, and many millions of florins would have been saved by this reduction in length and by the smaller number of costly tunnels, viaducts, &c., the same rule finding universal application which holds good in this special case.

F. C. F.

Accelerated Action of Air-Brakes.

A. P. KAPTEYN, Assoc. M. Inst. C.E.

(Tijdschrift van het Koninklijk Instituut van Ingenieurs, 1888–89, p. 103.)

The Author gives a complete review of the latest improvements in air-pressure brakes, and more particularly refers to the different devices which have been brought out during the last three years to accelerate the action of brakes on long trains. The Author first

refers to the Carpenter brake system, which was adopted in 1882 by the Prussian State railways on account of its apparent simplicity. It was found, however, that on long passenger trains the action was not sufficiently rapid, and it was proposed by the Westinghouse Brake Company and by Mr. Schleifer to improve its action by attaching to each cylinder an outlet valve. The Author shows the defects of the Schleifer arrangement, and points out that, in addition to inherent faults of this system, the great drawback of the use of the Carpenter or two-chamber system by the Prussian State railways lies in the fact that the surrounding States and railways, after exhaustive comparative trials, adopted the Westinghouse system, and that these two systems cannot be worked in the same train. The Author, therefore, designed a differential valve, which, if attached to each cylinder of the Carpenter system, gives the latter the same rapid action as that of the Westinghouse system. Actual trials with these valves were very successful.

The Author further describes his modified triple valve, by means of which the release of the Westinghouse brake can be graduated as well as its application, by allowing the pressure existing in the brake-cylinder to influence the equilibrium of the triple valve, but its details cannot be described without drawings.

The Author then describes the experiments with continuous brakes on long freight trains in the United States, which showed that continuous brakes as constructed in 1886 could not be satisfactorily worked on such trains. The different inventors of brakes endeavoured to improve their action, mostly by employing electricity as an auxiliary, so as to get absolute simultaneous action. Mr. Westinghouse, however, finally succeeded in modifying his well-known triple valve so as to obtain, without the aid of electricity, such a great rapidity of action that the brakes on the fiftieth vehicle acted in less than two seconds after the brake-valve on the engine was operated. The very successful and repeated trials with these improved brakes on various lines in the United States are described, supplemented by a Table of the results obtained.

The Author next describes his automatic time-pressure, speed and distance-recording instrument, by means of which the various results which are obtained with continuous-brakes are measured with the greatest accuracy, and adds several diagrams taken by this instrument.

Descriptions are given of several triple valves of different construction designed by the Author, by means of which the same rapidity of action as with the quick-acting Westinghouse brake can be obtained. Two graphical Tables are described, by means of which the time necessary for a stop, effected by means of brakes, can be easily calculated, and the Paper is terminated by an account of a new form of driver's brake-valve for the Westinghouse brake, which enables the driver to operate the brake on the longest trains with the greatest ease.

The Paper is fully illustrated. A. P. K.

The West-Point Tunnel. By W. H. SEARLES.

(Journal of the Association of Engineering Societies, 1889, p. 57.)

The railway, which follows the west bank of the Hudson River, passes by a tunnel under the projecting headland on which the military post of West Point is located. The shore is generally rocky and precipitous; and as the line approaches this point from the south, it keeps closely to the face of the cliff for some distance, being carried upon a ledge blasted out to receive it; then, after traversing an embankment in the river for a quarter of a mile, it enters the tunnel upon a 4°-curve which extends 600 feet beyond the mouth. The remainder of the tunnel is on a tangent, the total length being 2,664 feet.

The work was only completed in December 1882, its execution having been tediously delayed by financial troubles and by unexpected engineering difficulties.

The rock cuttings at the two approaches were commenced in June 1872, and the headings were started from each end of the tunnel in the following November and December. But in May 1873, the company was compelled to abandon the undertaking, and after working on until September, the contractor also stopped operations. At this date, the headings had been driven 180 feet and 196 feet respectively, and a portion of the length had been widened to full size; and in this condition the work remained untouched for a period of nearly seven years.

In August 1880, however, the contractor resumed his task under a contract with a newly-constituted railroad company; and the work was then pushed forward with great vigour. An engine and boiler-house were erected, and an air-compressor of 150 HP. was set in operation, the compressed air being led from the receiver to either end of the tunnel by 4-inch pipes. Ingersoll drills were employed, and electric lights were used in the headings.

During the winter, the exhaust of the drills was sometimes clogged with ice, the compressed air having been considerably cooled by its passage through the long pipes; but this was remedied by the use of a heating-chamber containing a few coils of pipe, through which the air was passed on its way to the drills. This not only prevented the formation of ice, but also increased the efficiency of the compressed air.

When everything was got into order, the progress in the south working averaged 119 feet per month for ten consecutive months, the maximum being 142 feet; and the work was carried on in two shifts of ten hours each per day. The headings were continued in the roof, and the enlargement to grade followed about 30 feet behind.

Up to this point, the material had been solid granite rock throughout. In the south working the rock contained few seams, and no water of any consequence; but in the north working it

was more seamy, and sometimes shattered and wet; and to make the roof of the tunnel safe, it was sometimes necessary to excavate unsound rock beyond the normal section. At one wet spot which had been discharging water and mud, the roof was propped with heavy timbers, and was supposed to be safe; but it suddenly fell in, leaving a ragged hole about 8 feet across, through which poured gravel and saturated sand until the tunnel was filled to the roof, while the slope extended nearly to the tunnel-mouth, 280 feet away. The subsidence was evidenced upon the surface by the formation of a conical hole 50 feet in diameter and 40 feet deep, undermining some of the buildings of the military station. No workmen were in the tunnel at the time; but one who was standing on the upper surface was drawn into the vortex and killed.

In excavating the detritus which had thus fallen in, it was found that as soon as the vent was freed the flow recommenced, and the surface funnel at once enlarged itself to 70 feet diameter and 60 feet depth. To choke the hole in the roof, large quantities of timber and brushwood were thrown into this cavity, until the movement of sand was arrested, and the sides of the cavity were then strutted by timbering. At the same time, a small timbered drift was pushed on through the detritus inside the tunnel until the original rock heading was reached.

The hole continued to discharge water, and, the roof being weak, the tunnel was lined with a brick arch for a length of 70 feet; but when this was completed, it was found that the arch leaked at the crown, the water being detained there by the timber bars which had been used for the temporary support of the roof (and left in when the arch was turned) so that it was prevented from reaching the drainage provided for it at the skew-backs. To intercept this water, a driftway was driven from the west side of the tunnel, returning towards the crown; but although this drew off a great deal of water, it failed to stop the leak, the contractor deeming it unsafe to carry the driftway as far as the crown.

After passing this weak point, the rock excavation was continued as before, until a drill working horizontally in the north heading broke through into sand, the rock having terminated with a steep face nearly at right-angles to the tunnel. This necessitated a change of operations; the drills and pneumatic appliances were withdrawn, and plant was prepared for tunnelling in sand, while preparations were made for lining the tunnel with a brick arch, side-walls and invert.

The south heading broke through into sand shortly afterwards, and there remained at this time a distance of 365 feet between the headings. Through this length of sand and quicksand the headings were driven until they met, and were carried somewhat above the crown of the intended arch, so as to leave room for a heavy timbering of the roof, the pressure of the sand being very great.

At the same time, a ditch, 3 feet in depth, was blasted out of the

rock floor of the tunnel to provide for the drainage of the invert upon this intervening length. The ditch was useful in drying the tunnel, but the intended invert was never required, for in excavating the tunnel it was found that the sand did not, at any point, extend so low as the formation level, which lies in solid granite rock throughout the entire length.

For the lining of this portion, a nearly elliptical brick arch was turned, having a span of 27 feet and a rise of 9 feet, and consisting of nine rings at the springing, reduced to six rings at the crown. At some points, the skew-backs were formed in the rock, while at others, the arch was supported upon brick side-walls carried down to the rock, which was found at some height above formation level.

When the sand was first met with, borings were taken from the surface to ascertain its extent and depth upon the intervening portion. These borings penetrated to different depths, but in every case the boring was stopped by the rock at a height of not less than 40 feet above the roof of the tunnel; and the Author regards the occurrence of the underlying bed of sand as proving the insufficiency of any borings that are not carried down to formation level.

The Paper describes also the timbering and centering employed in the work, and the details of monthly progress.

T. C. F.

Jull's Centrifugal Snow-Excavator.

(Railroad Gazette, New York, March 29, 1889, p. 209.)

This machine, the first built under the patents of Mr. Jull, was constructed by the Southwark Foundry and Machine Company, Philadelphia, and has recently been subjected to trial on the Rome, Watertown, and Ogdensburg Railroad. In principle it constitutes a radical departure from the well-known rotary snow-shovel, the cutting-plates being placed spirally on a cone, the whole having the appearance of a gigantic three- or four-bladed auger-tip. It is placed diagonally across a rectangular hood or case, in such a way that the gearing by which it is driven is at the top of the off side of the hood while the block taking the thrust of the auger is at the bottom of the near side of the hood. The blades have a sharper pitch towards the apex than at the base of the cone, and are convex, so as to carry the snow back as it is cut off. The snow is discharged through openings at the top of the hood, and may be thrown out on either side of the track, according to the direction of the wind. The auger is driven through bevel-gear by two engines, having 18 by 24-inch cylinders. The boiler has two hundred and twenty tubes, and its capacity is estimated at 800 HP. The machine, in complete working order, has a calculated weight of 65 tons, and is 50 feet long over all. The weight of the auger is about 6 tons, and of all the machinery forward

the truck supporting the driving-engine, 20 tons. With the ›d in its normal position, the width of the cut is 10 feet, but achable wings are provided which can be put on after the it cut is made, and so considerably increase the width of the ›avation. It is intended to run the machine at 320 revolutions ninute, though so far the speed has been under 200 revolutions.

In the trials referred to, which took place near Oswego, New York, the 11th of March, 1889, the excavator was pushed by two loco- ›tives, one having 16 by 22-inch, and the other 17 by 24-inch linders. The test was made on a siding on which the snow had accu- ılated to a depth of from 2 to 10 feet, and the rails were heavily ıted with ice. The excavator was not equipped with flangers, and was stopped three times in clearing 720 feet. Deducting the time nsumed in these stops, the excavation was made in seven minutes, e snow being thrown out in a sheet 4 feet wide, to a distance of ›out 60 feet. Mr. Bowen, the general manager of the railway, timated that it would have taken a day's work of one hundred en to clear the same piece of track.

An illustration of the excavator accompanies the original ›scription.

F. G. D.

Compound Locomotive on the Northern Railway of France.[1]

By G. du Bousquet.

(Revue Générale des Chemins de fer, November, 1888, p. 285.)

On the advice of Mr. du Bousquet, an eight-coupled wheel goods ›comotive, on the Northern Railway of France, was converted ıto a Woolf tandem compound locomotive, comprising a pair of ındem engines. In making this conversion, the application of lditional wheels was not allowed, and the maximum weight on ny one axle was not to exceed 14¼ tons (14½ tonnes), the maximum reight allowed for high-speed engines on the railway. The dis- ribution of the weight of the locomotive before and after conversion ras as follows:

	Before Conversion.	After Conversion.
	Tons.	Tons
1st axle	12·00	13·24
2nd „	10·92	14·01
3rd „	11·91	13·76
4th „	9·15	9·86
	43·98	50·87

Showing an augmentation of 7 tons weight, of which 3 tons is

[1] An illustrated description of this engine occurs in the "Railroad Gazette," N.Y., March 8, 1889.

the weight of a platform of cast-iron, at the back of the fire-box, to counterbalance the weight of the cylinders.

The cylinders of the original engine were 19·68 inches in diameter, with 25·59 inches length of stroke; and wheels 51·18 inches in diameter. As compounded, the first and second cylinders, in tandem, were 15 inches and 26 inches in diameter, with the same stroke as before, 25·59 inches; the capacity-ratio of the cylinders being 3. These dimensions are the result of elaborate calculation based on indicator diagrams taken from the cylinders of the original engine. The cylinders are outside the frame-plates, and the second or larger cylinder is placed at the front. They are joined together forming a diaphragm partition common to both; and the second piston is provided with two piston-rods, which pass back, flanking the first cylinder, and are, with the piston-rod of the first cylinder, fastened to a cross-head common to both. The two cylinders have but one valve-chest and one slide-valve, worked by the link-motion. The valve is formed double to provide passage ways between the cylinders, and for the exhaustion into the chimney. For the second cylinder the Trick principle of double entry is provided. The steam-ports are unusually wide, 17¼ inches, for ready ingress and egress of steam. The valve is balanced, for the most part, by the removal of the pressure on the back by a packing-ring for a circular area 19 inches in diameter. Through an automatic piston-valve, air is admitted into the cylinders when the steam is shut off. Steam can be admitted direct into the second cylinder when required.

During the month of January, 1888, the compound locomotive was tested daily with regular coal trains of sixty wagons (900 tons), from Lens to Longueau, 106 miles going and returning. The gross consumption of fuel was at the rate of 50 lbs. of coal per mile. By the results of comparative trials of the ordinary and the compound locomotive, given in detailed Tables, it is shown that a saving of fuel, of from 13½ per cent. to 26 per cent. according to the weight of the trains, is effected in favour of the compound system. These results, deduced from the actual performance of the engines, are corroborated by analyses of the indicator diagrams, which show an economy of from 3·2 per cent. to 26·4 per cent.; with speeds of from 10 miles to 13 miles per hour on levels and ascending inclines for the ordinary machine, and from 8 miles to 22 miles per hour for the compound machine.

D. K. C.

Domestic Motors worked by Rarefied Air. By L. Boudenoot.

(Mémoires et Compte-rendu de la Société des Ingénieurs civils, February 1, 1889, p. 68.)

Mr. Boudenoot's earlier accounts of the system of supplying power for domestic motors, by rarefied air, have already been

noticed.[1] In 1885, fifty of the air motors were in operation; and the vacuum was maintained by means of an exhausting engine. At present, there are from one hundred and twenty to one hundred and fifty motors of ½ HP., 1 HP., and 1½ HP., placed at from 2,000 to 2,500 feet distant. There are three exhausting engines, of from 90 HP. to 100 HP. There is, in addition, a steam-engine of 110 HP., by which are driven two dynamos supplying from 1,200 to 1,500 electric lamps placed in the neighbourhood; Mr. Boudenoot shows, that amongst the various means of transmission of power: cables, steam, water under pressure, gas, electricity, and air, this last alone is worth considering, when it is required at the same time to transmit power over a short distance, and to subdivide it for local distribution. He adds, that whilst rarefied air yields from 40 to 45 per cent. of efficiency, compressed air under like conditions, yields from 18 to 22 per cent.

At the central station, the india-rubber packing applied to the pistons of the air-cylinders has been replaced by bronze packing. The india-rubber packing wore out quickly, and leakage took place between the two sides of the piston; the separated lumps of india-rubber were agglutinated with the dust drawn in and blocked the grids of the valves. With bronze, the first objection disappeared, and the collection of dust was diminished. The grids are cleared three or four times yearly. In the presence of dust, the clack-valve is preferred to the slide-valve; the latter is liable to excessive friction and wear due to the interposition of dust. The air-cylinders are cooled by means of fine spray or water-mist injected into them, in preference to water applied externally; and the pumps are worked slowly. A vacuum alarm is employed, by means of which the operations of the machines are so regulated, that a constant vacuum is maintained at the extremities of the conduits, notwithstanding the variation of the demands of the users. The revolutions of the motors are registered by means of an apparatus, which shows from hour to hour the variations of the work done by the motors; and the total number of revolutions made each month. These instruments, with the vacuum-gauges placed at various points, constitute a very useful set of controlling apparatus. With regard to the loss of head in the pipes, the formula of Stockalper, $J = a\ Q^2\ \delta$, has proved to be approximately correct in practice.[2]

Of the three forms of motors employed, the oscillating, the rotative, and the trunk, the last alone is now in use, and there are now trunk motors of—

NOMINAL WORK PER MINUTE.

100 kilogrammetres	(or 43,500 foot-pounds),	which yield	more than	1½ HP.
50 „	(or 21,750 „),	„	nearly	1 HP.
25 „	(or 10,875 „),	„		½ HP.

[1] Minutes of Proceedings Inst. C.E., vol. xc. p. 527; and vol. xciii. p. 571.
[2] *Ibid.*, vol. lxiii. p. 348.

The motors are tested at the works before being hired out. The performance of a 50-kilogrammetre motor, for example, as tested, was as follows—

Condition.	Air per Minute.	Pressure.	Power Developed in the Cylinder.	Power Developed at the Brake.	Efficiency of the Motor.
	Cubic Inches.	Atmosphere	Foot-pounds.	Foot-pounds.	Per cent.
Light work	427	0·282	358	243	68
Medium „	671	0·414	489	397	81
Full „ normal . .	976	0·540	587	514	88

It is expected that the rarefied-air system will be adopted at St. Etienne, for the use of the lacemakers, where hydraulic power is available for working the pumps.

The electric-lighting installation comprises a horizontal Corliss steam-engine of 110 HP., two Gramme dynamos of 370 amperes and 110 volts, with the transmission necessary for a distribution of 200 volts to three conductors, with the lamps.

D. K. C.

The Theory of Aqua-Ammonia Engines. By E. E. MAGOVERN.

(Transactions of the American Society of Civil Engineers, vol. xix, 1888, p. 127.)

From general considerations the Author concludes that there is nothing, in the science of thermodynamics, which precludes the possibility of obtaining a less wasteful medium than water for the conversion of heat into mechanical energy. He then gives a description of a plant for the utilization of ammonia in engines, and of experiments made with it. The boiler is of the horizontal return-tube type, with a superheating surface. A division-plate is introduced in the back connection so that the products of combustion pass forwards through the liquid, and return above through the vapour. The boiler was worked with artificial draught. The feed-liquid is supplied by a fly-wheel pump discharging through two heaters and a coil. The motor is a Porter-Allen engine, unjacketed; diameter of cylinder, 11·5 inches; stroke, 20 inches. The load on the engine consisted of two Edison dynamo machines of 225 amperes capacity each. The engine also drove the fan and feed-pump. The absorbing apparatus consists of a jet of spray from the boiler introduced into the exhaust-pipe. The liquid forming the spray is first cooled in the heaters. After leaving the spray-jet the exhaust vapour passes to the first absorber, which is practically a surface-condenser with five hundred ⅝-inch tubes, 41 inches long. The vapour then passes into the second absorber with one hundred

and fifty tubes, 40 inches long. Here the vapour is nearly or wholly converted into liquid which overflows into a well, from which it is returned to the boiler by the feed-pump. The absorbers are cooled by a current of water supplied from the city hydrant, and partly by a small centrifugal pump fed with sea-water. Tests showed that the piston of the engine was tight, but that the exhaust-valves leaked, and this operated against the efficiency of the engine.

Experiments were made in this way. The apparatus was worked first with steam and then with ammonia, and the results were compared. With steam only 32·26 HP. could be obtained, but with ammonia used in the same boiler, 58·14 HP. were obtained at a lower rate of combustion.

With steam the consumption of coal was 5·626 lbs. per HP. per hour; with the ammonia the consumption fell to 2·974 lbs. per HP. per hour. The poor boiler performance affected the results of both fluids equally. The Author believes that much water is evaporated in the boiler with the ammonia.

W. C. U.

Progressive Trials of the Steam-Barge of the Commandant of the New York Navy-Yard.

By Chief-Engineer B. F. Isherwood, U.S.N.

(Journal of the American Society of Naval Engineers, 1889, p. 1.)

In November 1888 a series of progressive trials were made with this barge, to determine the resistance of the hull at various speeds.

The dimensions of the barge are as follow:—Length on water-line, 50 feet; breadth on water-line, 10 feet 6 inches; mean draught of water, 3 feet ½ inch; area of greatest immersed transverse section, exclusive of keel, 18·96 square feet; area of wetted surface, 533 square feet; displacement at load draught, 17·38 tons. It is propelled by one set of vertical compound engines, fitted with Joy's valve-gear. The brass propeller is of the modified Griffiths type, the tips of the blades when vertical being 9 inches below the surface of the water.

The runs were made on a course 3 geographical miles long, the speed being taken by a tested patent taffrail log. Observations were made of the pressures, temperatures, &c., a set of cards was taken for each mile, and the revolutions were registered by a counter.

Various assumptions are made as to the internal friction of the engines, surface friction of the propellers, &c., upon which to base a calculation of the true thrust of the screws upon the water.

This is calculated from the indicated HP. as follows. A deduction having been made for the power expended in driving the engines unloaded, for the friction due to the load, for the surface friction of the propellers, and the power expended on the slip,

the remainder is the power expended in the propulsion of the vessel pure and simple. Dividing this power in foot-pounds by the speed of the ship in feet per minute, the thrust of the screw in pounds is obtained.

The speeds at which the barge was tried were, by log, 4·27, 5·58, 6·53, 6·9, 7·57, 8·52, and 8·85 knots. From these trials it was found that, taking the thrust of the screws as above, the resistance of the vessel as a function of its speed remained about constant up to 7·5 geographical miles per hour. Up to this speed the resistance of the hull varied on the average as the 2·47th power of the speed. Beyond this speed the resistance increased in a very much higher ratio, due to the "squatting" of the hull at the stern. The Author further explains this "squatting" by a consideration of the direction of flow of the current in the wake, with the consequent modification of the slip and direction of thrust of the screw.

D. S. C.

Regenerator-Condenser. By — Hirsch.

(Bulletin de la Société d'Encouragement, 1888, p. 453.)

The regenerator condenser consists of a double condenser and a refrigerator for cooling the water employed in condensing the steam, whereby the same condensing water may be employed over and over again. The apparatus is named in the original, *Condenseur double à eau régénérée*, and is the invention of Messrs. Chaligny and Guyot-Sionnest. The steam exhausted from the engine is received and condensed in an ordinary jet-condenser, from which the hot water is sent by the air-pump to the refrigerator, where it is cooled and stored for service anew in the jet-condenser. The second, or supplementary condenser, is multitubular surface-condensing, through the tubes of which the exhaust-steam passes, and is partly condensed by the condenser-water which traverses the tubes externally, on its way from the jet-condenser to the refrigerator. Whilst the steam is condensed, the water, on the contrary, gains in temperature, a part of the water being intercepted for feeding the boiler.

The refrigerator is the capital feature of the system. It consists of a sort of cataract, or waterfall, constituted by fascine work arranged in stages vertically in a vessel, through which the water falls from one to another. The water is thus minutely subdivided, and is in this condition exposed to the blast of a fan blower, which passes from below upwards. Refrigeration takes place by evaporation and by contact. The quantity of water thus evaporated is nearly equal in weight to the exhaust-steam, leaving undiminished the supply of condensing-water. Thus the condensation costs nothing for water.

The leading comparative results of nine-hour trials made in 1886, with a semi-portable compound steam-engine, successively

non-condensing and condensing, on the regenerative system, and developing about equal powers, were as follows:—

		Non-Condensing.	Condensing.
Period of admission	per cent.	55·00	36·70
Indicated HP.		30·66	29·38
HP. at brake		24·25	24·12
Water evaporated per indicated HP. .	lbs.	24·50	14·60
„ „ „ HP at brake .	„	31·00	18·10
Coal consumed per indicated HP. . .	„	2·85	1·91
„ „ „ HP. at brake . .	„	3·63	2·38

The vacuum, in the second case, was 19·65 inches of mercury; the pressure in the refrigerator was 0·12 inch (3 millimetres); the temperature of the feed-water was 50° Fahrenheit, of the water leaving the condenser 137°, of the external air 68°, and of the air leaving the refrigerator 101°·4.

D. K. C.

Lifting-Jack with an Automatic Brake. By F. ENGEL-GROS.

(Bulletin de la Société Industrielle de Mulhouse, 1888, p. 577.)

The object of the automatic brake constructed by the Alsatian Society of Mechanical Construction, Grafenstaden, and applied to rack-jacks, is to prevent accidents when the workman happens to lose hold of the crank whilst the apparatus is loaded and the detent is being taken out of gear. A circular mass of cast-iron is mounted as a sleeve on a short steel shaft, the end of which is formed as a pinion, which gears with and is driven by the first wheel of the rack. The part of the shaft within the circular mass is cut as a screw of long pitch, with several threads, and engages the interior of the circular mass, which is carried round with it. Under ordinary circumstances the mass is held in its proper place by means of a helical spring; but, when the machine accidentally commences to run down at a quick speed, the circular mass is induced by the screw, overpowering the spring, to slide endwise on the screw, and to come into frictional contact with a fixed conical surface. The descent is thereby almost instantaneously arrested. In lowering at low speeds, the spring is sufficiently stiff to maintain the circular mass, in all positions of the jack, out of contact with the friction-surface.

D. K. C.

Comparative Trials of Piston-Pumps and Centrifugal Pumps. By — DE GLEHN.

(Bulletin de la Société Industrielle de Mulhouse, 1888, p. 661.)

The establishment of Messrs. Schaeffer, Lalance, and Co., at Pfastatt, uses daily from 8,000 to 10,000 cubic metres of water,

drawn, until 1885, from the River Doller, by means of ten centrifugal pumps. To obtain a supply of water of a temperature more nearly constant, a well was sunk in the water-bearing strata near the river, from which from 20 to 45 gallons per second were drawn by means of two "conjugated" centrifugal pumps, supplied by Messrs. Neut and Dumont. Subsequently the means of supply were extended, and piston-pumping engines were constructed capable of drawing and delivering 90 gallons per second into the tank already constructed for the centrifugal pumps. The opportunity was embraced of making test-trials of the two systems of pumping—by centrifugal pumps, and piston-pumps—under identical conditions, from the same well with the same lift, by the same discharge-pipe, into the same tank, of large capacity. The discharge-pipe delivered the water over the edge of the tank, and the head of pressure was, therefore, constant, whatever might be the level in the tank.

The centrifugal pumps were erected in 1872, and had worked till the time of the trials, in May, 1888, without needing repair. The suction-pipe was about 12 inches in diameter, and the delivery-pipe 10 inches. But, to deliver the required quantity, 37 gallons per second, through an average height of 39·4 feet, the pumps were "conjugated," so that one followed the other in succession, and could perform the required duty at a speed of 520 turns per minute. The steam-engine employed to drive the pumps had a cylinder 21·65 inches in diameter, with a stroke of 39¾ inches. The revolutions of the pumps were recorded by a counter. Each trial lasted from 4½ minutes to 7½ minutes. The leading results were as follow :—

DUTY of CONJUGATE CENTRIFUGAL PUMPS.

Trial	L.	M.	N.	O.
Speed of engine, in turns per minute .	45·9	49·6	52·6	60·0
" pumps, " " .	470	506	538	611
Mean lift . . . . feet	35·51	35·59	35·64	35·71
Duty in water lifted per turn of engine / Indicated work in cylinder, for one revolution . . . . } foot-lbs.	15,549	16,448	17,741	19,589
	32,125	37,105	43,000	56,419
	Per cent.	Per cent.	Per cent.	Per cent.
Duty, percentage of engine-power . .	48·4	44·3	41·25	34·72

The piston-pumps and steam-engine were constructed by Messrs. Hathorn and Davey, Leeds: a horizontal compound receiver steam-engine, connected by bell-cranks to four pumps in the well. The first cylinder is 19 inches in diameter; the second is 33 inches in diameter; the stroke common to both cylinders is 36 inches. The pistons of the pumps are 22 inches in diameter, with the same stroke as the engine, 36 inches. The pumps work well and without shocks, at speeds up to 20 revolutions per minute.

The engine and pumps together, with the carriage, duty, and erection, cost £2,160. The total weight was 69 tons, costing £31 6*s.* per ton.

The trials, nine in number, lasted from 3½ minutes to 7 minutes. The leading results are given in the annexed Table:—

DUTY of PISTON-PUMPS and ENGINES.

Trial . .	A.	C.	D.	E.	F.	G.	H.	I.	K.
Speed, in turns per minute .	13·44	20·3	18·4	22·7	24·5	26·1	18·7	16·3	13·3
Mean lift, feet	35·45	36·03	36·23	36·41	36·52	36·60	36·21	36·31	36·19
Duty in water lifted per turn, foot-lbs. . .	69,586	71,079	71,434	71,789	71,753	72,195	70,716	70,919	71,405
Indicated work in cylinder for one turn, foot-lbs. . .	99,035	103,689	101,311	106,220	106,680	111,686	102,326	99,202	96,715
Duty, percentage of engine power . .	Per cent 70·26	Per cent. 68·55	Per cent. 70·5	Per cent. 67·9	Per cent. 67·4	Per cent. 64·6	Per cent. 70·0	Per cent 71·46	Per cent. 73·8
Ratio of water actually lifted to calculated quantity . .	0·992	1·0	0·998	0·998	0·995	0·998	0·998	0·990	1·0

It is notable that the percentage of duty decreases as the speed of the engine and pumps increases, thus—

In the trials

K A I D H C E F G

the speeds in turns per minute were—

13·3 13·4 16·3 18·4 18·7 20·3 22·7 24·5 26·1,

and the percentages of duty were—

73·8 70·2 71·4 70·5 70·0 68·5 67·9 67·4 64·6.

D. K. C.

Hand-Power Machines for Rock- and Coal-Boring.

By — DINOIRE and — MAILLARD, Engineers at the Lenz Mines.

(Bulletin de la Société de l'Industrie Minérale, 1888, vol. ii. p. 305.)

The Authors point out that while percussive drilling-machines are the most suitable for piercing hard rock, yet in softer materials, easily disintegrated, the *débris* tends to choke the hole, jam the drill, and cushion the blow. In such cases a rotary boring-tool is obviously the most suitable, but its adoption is attended with another class of difficulties, chief among which is the difficulty of arranging a suitable feed-motion for advancing the bit, especially

when attacking strata of varying hardness, each of which can be best pierced at one special rate of advance. Any feed-motion requiring the constant or frequent attention of a workman obviously detracts from the efficiency of the tool; it is, therefore, essential that the feed should not only be automatic, but also self-regulating and self-adjusting to suit the resistance met with.

Most of the machines designed for this purpose bear a general resemblance to each other, and consist of a stand adjustable between roof and floor, either by a slide or screw, on which the drill proper, consisting of a screwed spindle working through a nut, with a socket for the boring-bit at one end and a square at the other for the crank-handle or ratchet, can be fixed at any convenient height or angle.

In the "Elliot" drill the nut is replaced by a worm-wheel, in the teeth of which the feed-screw (which has a square thread of ½-inch pitch), takes its bearing. This wheel, or rather collar, is carried in a ring, which, by means of a hinged joint and clamping-screw, holds it with more or less friction. If the resistance is excessive the collar commences to slip round to a certain extent, thus reducing the full advance of the drill, which may vary from ½ inch per revolution to *nil*. By slacking the clamping-screw the drill can at once be withdrawn without being wound back. The chief objection to this arrangement is that the teeth of the worm, and the opposite side of the guide box through which the screw passes, are subject to considerable wear.

In the "Charbonnière" of Mr. Bornet (a modification of his earlier machine, the "Cantin"), which is of larger and heavier proportions, the crank-handle is fixed at right-angles to the drill-spindle, which it drives by a pair of bevel-wheels geared in the ratio of 1 to 4. The nut in which the feed-screw works is seated in a spring-box, so that, with an increase of pressure when working in hard strata, the feed is equal to the pitch of the screw less the amount of compression of the springs. When these are fully compressed the nut slips out of its bearing and revolves with the screw, the feed being given solely by the spring-pressure until the nut again engages in its seat.

The "Jubilee," by the same inventor (which is illustrated, but not described in detail), is of simpler form without the bevel-gearing, but reversible.

The Authors appear to give the preference to the "Universal," by Mr. Sartiaux, of Hénin-Liétard, in which the elasticity of the standard itself enables springs to be dispensed with, and regulates the pressure. The nut, of phosphor-bronze, is carried in a split steel sleeve with pinching-screw, and is fitted with hardened steel collars bearing on the sleeve at either end. The thread is double, of rounded contour, and ⅜-inch pitch. As the pressure increases, the friction of the screw-threads on the nut becomes relatively greater than that of the collar of the nut on the sleeve, plus the grip of the sleeve, the two latter frictions both tending to prevent, and the former to effect, the rotation of the nut simultaneously with the screw. The first

and second of these frictions evidently bear some proportion to the pressure, while the third is independent of it; and the successful result depends on the correct proportions of the various parts, and especially on the pitch of the screw and the form of its threads, and its diameter as compared to that of the nut in the sleeve; these being again to some extent modified by the modulus of friction of phosphor-bronze and steel respectively, the correct result being only attained after actual trials and experiments.

A few remarks respecting the use of explosives, and of wedges for breaking down the coal, are appended.

W. S. H.

Note on the Construction of Cylinders for Hydraulic Presses and Compressed-Air Lifts, with the various calculations connected therewith.

By A. Barbet, Chief Engineer of the Société Cail.

(Mémoires et Compte-rendu de la Société des Ingénieurs Civils, 1888, p. 565.)

The above article treats of the materials in general use for the construction of hydraulic-press cylinders, with their advantages and disadvantages, as well as the details of the construction of the press-cylinders themselves. The materials, of which the peculiarities are described, comprise cast-iron, wrought-iron and steel, cast-steel, bronze, and mention is also made of press-cylinders built up of iron and steel plates. Numerous examples are cited of existing presses, such as those used in erecting large bridges, and calculations are given showing the strains on the metal due to the working pressure. The effect of the different methods of admitting the water under pressure into the cylinders is fully entered into, as some cases are cited in which failure of hydraulic lifts has been attributed to defective admission of the water. Mathematical researches into the effect of unavoidable oscillating movements in long hydraulic presses are treated in one section of the article, and a number of formulas, both theoretical and practical, are given. The article is illustrated by a large sheet of drawings, showing the construction of many of the most notable hydraulic lifts, press-cylinders and rams in detail.

H. H. P. P.

On the Friction of Small Spindles at High Speeds.

By R. Bourcart.

(Bulletin de la Société Industrielle de Mulhouse, 1888, p. 720.)

Having referred to a previous communication on the same subject, in May, 1886, Mr. Bourcart now shows that the coefficient of friction, in driving small spindles by cords, is an inverse func-

tion of the total pressure of the cord on the spindle. This result has been obtained by experiments with spindles from $\frac{1}{4}$ inch to $\frac{3}{8}$ inch in diameter, driven at speeds varying from 7,000 turns to 17,000 turns per minute, by an endless cord from a 32-inch pulley. The cord, in advancing towards the spindle, passes, with the aid of two guide-pulleys, under a weighted pulley, subjecting the cord to the required degree of tension, and it returns from the spindle-pulley, which is 0·79 inch in diameter, direct to the driving-pulley. There are simple means of maintaining the axis of the spindle in a vertical position.

Representing the tensions in the two limbs of the cord by T and t respectively, T for the returning limb, t for the advancing limb, $(T + t)$ is the sum of the tensions, or the total stress on the spindle; and $(T - t)$ is the difference of the tensions, or the frictional resistance; whence $\frac{T - t}{T + t}$ is the coefficient of friction. By varying the load on the weighted pulley, the values of T and t are varied likewise; and it is shown, by the results of the experiments, that the coefficient of friction of steel on cast-iron surfaces lubricated with oil diminishes as the total pressure is augmented. For instance, a $\frac{1}{4}$-inch steel spindle revolving in a cast-iron socket, driven at a speed of 15,500 turns per minute, was weighted to give the approaching tensions noted in the following column t; and the respective coefficients of friction were as noted in the column $\frac{T - t}{T + t}$.

t.	$\frac{T - t}{T + t}$.
0·170 lb.	0·369
0·220 ,,	[illegible]
0·280 ,,	0·298
0·390 ,,	0·269
0·611 ,,	0·208
0·831 ,,	0·180
1·051 ,,	0·170
1·272 ,,	0·160

Like results are given in the Paper for other diameters of spindle and for other speeds.

D. K. C.

Bibliography of Mining. By H. S. Munroe.

(The School of Mines Quarterly, New York, 1888, p. 176.)

In this list only the more valuable works on mining are included. Works on economic geology, and mining reports are not included in the list. The books are classified under the following heads: General treatises on mining, mining machinery, metal mining, elementary treatises on mining, popular works on mining, societies, mining journals, Government and State reports, indexes to periodical literature, mine-surveying, hydraulic mining, drilling and blasting,

well-boring, shaft-sinking, tunnelling, mine-timbering, mine-ventilation, mine-drainage, haulage and surface-transport, ore-dressing and coal-washing.

B. H. B.

The Mineral Resources of New South Wales.

By H. Wood, C. S. Wilkinson, and J. Mackenzie.

(Mineral Products of New South Wales, Notes on the Geology of New South Wales, and Description of the Seams of Coal worked in New South Wales. Sydney: Department of Mines, 1888.[1])

This volume, which is the second edition of a work published by the Department of Mines in 1882, brings up to the end of 1886 all the available information concerning the geology and mineral products of New South Wales. The progress made in the development of the mineral resources of the colony is shown by the following statistics, giving the value of mineral raised:—

	£.
During ten years ending 1855	6,766,970
" " " 1865	16,001,154
" " " 1875	19,108,175
" " " 1885	24,792,839

The mineral statistics for the year 1886 were as follow:—

	Quantity.	Value. £.
Gold	101,415 ozs.	366,294
Coal	2,830,175 tons	1,303,164
Shale	43,536 "	99,976
Copper and regulus . .	4,026 "	167,665
Tin and tin ore . . .	4,967 "	467,653
Silver	1,015,433 ozs.	197,544
Silver lead ore . . .	4,802 tons	294,485
Iron	3,685 "	19,086
Antimony and ore . .	237 "	3,381

Previous to 1851, coal was the only mineral raised, and of this mineral New South Wales claims to possess the richest, most accessible, and most extensive deposits in the southern hemisphere. The coal-measures cover an area of 23,950 square miles. The seams worked vary from 3 to 25 feet in thickness; they are nearly horizontal, and in many localities considerably above sea-level. There are forty-one collieries at work, affording employment to four thousand one hundred and twenty-five miners. Besides the collieries, there are two mines at which valuable seams of boghead mineral are worked, the number of men employed being two hundred and thirty-one. There are three principal coal-mining

[1] The original is in the library of the Inst. C.E.

districts, the Hunter River and Newcastle coal-field, the Southern or Illawarra coalfield, and the Western or Lithgow coal-field. In Mr. J. Mackenzie's report, descriptive diagrams are given of all the seams yet opened, and in a report by Mr. W. A. Dixon, reprinted in that of Mr. H. Wood, analyses are given of forty-four specimens of New South Wales coal; and, for purposes of comparison, one hundred and ninety-eight analyses have been collated of coals from the principal coal-fields of the world. At the mines of the Australian Kerosene-Oil Company, a coal-cutter of the Gartsherrie type (a plan and section of which are given) is used for undercutting the seam of boghead mineral. The latter is worked on an advancing long-wall system, 250 feet in width, the waste being kept built up to within 6 feet of the face, leaving six roads for the transport of the mineral.

The quantity of gold produced since its discovery, in 1851, in New South Wales, has amounted to 9,673,389 ounces, valued at £36,102,844. The number of miners at present engaged is five thousand nine hundred and eleven, of which four thousand and nine are employed in alluvial mining, and one thousand nine hundred and two in quartz mining. The area occupied by auriferous formations is 70,000 square miles, or nearly one-fourth of the colony. The reefs generally vary from a few inches to 10 feet in width, and the gold rarely occurs without admixed pyrites. For this reason, New South Wales affords a promising field for the introduction of efficient methods of extracting gold from pyrites. Most of the gold hitherto raised has been obtained from alluvial deposits. From the wash-dirt of the Pliocene river-drifts, or "deep-leads," 1 ounce of gold per load is not an unusual return. Many of these leads have been followed into deep ground, until the ordinary appliances have proved insufficient to cope with the heavy influx of water; but as the difficulties encountered may be obviated by employing steam-power and improved gold-saving appliances, these leads will doubtless be again worked. On the Mount Brown gold-field, where there is a scarcity of water, large quantities of gold have been obtained by dry blowing. Two machines, recently invented for this purpose, have proved successful on trial. In view of the large area occupied by auriferous formations, and of the deposits not yet worked out, gold-mining in New South Wales may be regarded as an important permanent industry.

In the Report a detailed list is given of the deposits of the ores of copper, tin, iron, silver and lead, antimony, zinc, chromium, manganese, cobalt, bismuth, tungsten, and mercury, as well as of the deposits of asbestos, barytes, alumstone, building-stone, and diamonds and other gems. Since 1884, silver-lead mining has become one of the most important branches of the mining industry of New South Wales. Diamond-mining, too, is likely to become of much importance. Upwards of fifty thousand diamonds have already been obtained, the largest weighing 16·2 grains.

The Report is accompanied by twenty-two large folding plates, including a geological map of the colony, a map showing the

localities of the principal minerals, a map of the coal-fields, a diagram showing the annual mineral production from 1851 to 1885, and a number of colliery plans and sections.

B. H. B.

Statistical Returns relating to the Mining Industries of Russia for 1886.

Compiled from Official sources by S. Kouleebin.

(Sbornik statisticheskich svedeni o gornozavodskoi promishlenosti Rossei, 1886. 8vo. St. Petersburg, 1888.)

This book, of three hundred and forty pages, consists of a series of tables, accompanied by very brief explanations, in which are set forth, in the greatest detail, the statistics relating to the mining industries of the Russian empire for the year 1886.

At the commencement is a summary of the quantity of minerals obtained, with a brief notice of the localities in which they are worked. The quantities are as follow:—

Gold	73,516 lbs.
Platinum	9,488 "
Silver	29,169 "
Coinage—	
Gold	27,055,175 roubles.
Silver	1,510,553 "
Copper	100,000 "
Lead	753 tons.
Copper	4,430 "
Zinc	4,066 "
Tin	16½ "
Ores of manganese	72,097 "
Coal	4,434,816 "
Naphtha	1,911,248 "
Mineral pitch	130 "
Pig-iron	515,625 "
Wrought-iron	351,783 "
Steel	234,317 "
Iron castings	61,520 "
Enamelled ware	1,399 "
Steel and ironwork	50,172 "
Salt	1,159,936 "
Sulphate of sodium	4,328 "
Sulphur	1,111 "
China clay	5,416 "
Number of miners	356,283

The Tables comprise a vast amount of information relating to the internal and external trades in mining products, to the consumption of fuel on railways, the coinage, and other matters.

W. A.

Shaft-sinking at the Houssu Colliery, Belgium, by the Poetsch Freezing-Process.

(Bulletin de la Société de l'Industrie Minérale, 1888, vol. II. p. 21.)

The No. 8 shaft of the Houssu Colliery, 13 feet clear diameter inside the lining, had been sunk in the ordinary manner to a depth of 32½ fathoms, or 195 feet, without any special difficulty. At this depth, however, the solid floor, which was subsequently estimated to be about 5 feet thick, was suddenly upheaved with great force, giving vent to a very wet quicksand, which rose some 20 feet in the shaft, above which the water rose to within 82 feet of the surface. Including the 20 feet forced upwards, it was found that 62 feet of this quicksand had to be pierced before reaching a solid stratum.

On the advice of Mr. Poetsch, the shaft was plugged by a thick bed of concrete resting on the sand, and above this was chambered out about 3 feet on all sides. In this annular space eighteen freezing tubes were driven down right through the sand, and some 8 to 10 feet into the solid carboniferous strata below. These tubes were 6 inches bore, and each contained an inner tube of 2 inches bore, through which the freezing liquid descended, returning up the annular space. The outer and inner tubes were respectively connected by two tubular rings, from each of which a pipe, carefully lagged to prevent the absorption of heat, was carried to the surface and coupled to the freezing and circulating apparatus. During the freezing process no attempt was made to keep down the water in the shaft.

Owing to the inefficiency of the freezing-apparatus, and various other causes, it was a full year from the commencement of the process in 1886 before sinking could be resumed. A shaft 11 feet square was then sunk through the cement plug and the frozen ground down to the solid. This was carried out by three gangs of four men each, relieving each other every six hours; but, owing to the hardness of the frozen ground, only 18 inches a day could be achieved. All the work was done by pick and drill, no blasting being permitted for fear of breaking the freezing-tubes and dislocating the frozen casing, the thickness of which round the shaft was estimated at about 10 feet. An attempt was made to thaw out the core by steam-jets and a boring apparatus, but this was soon abandoned, as it was cumbrous and difficult to work, and produced a soft mud into which the miners sank to mid-leg, and progress was actually retarded. The artificial rock was so firm that the necessary scaffolding and timbering was carried on projections and cornices carved out of the frozen ground itself.

At a depth of 255 feet the square shaft was enlarged for the reception of three curbs, one of wood and two of iron, from which a lining of cast-iron tubbing 13 feet clear diameter, and 1⅝ inch thick, backed by a layer of concrete 10 inches thick, was carried

up without any difficulty whatever, the shaft being enlarged as the work proceeded. Ordinary cement was found to set perfectly, the freezing having no injurious effect upon it. An admixture of sea-salt was tried, but found to be unnecessary.

The refrigerating apparatus, which can scarcely be explained without reference to the drawings, is fully described and illustrated. It is on the Carré principle, a solution of ammoniacal salt of 29° Baumé, with a density of 0·88, and a strength of 36 per cent., being employed at a pressure of 10 atmospheres. The liquid circulating in the freezing-tubes is a solution of chloride of calcium of 21° Baumé, containing 23 per cent. of anhydrous chloride of calcium, congealing at − 40° Centigrade (− 40° Fahrenheit). Its temperature as pumped in is − 14° Centigrade (+ 7° Fahrenheit), that of the return current being − 10° Centigrade (+ 14° Fahrenheit); that of the frozen ground − 8° Centigrade (+ 18° Fahrenheit); and that of the air at the shaft-bottom, warmed by the lamps and the breath of the workmen, from − 1° to − ½° Centigrade (+ 30° to + 31° Fahrenheit).

The Paper is further illustrated by a section of the shaft, taken at the time when half the iron tubbing had been fixed; and particulars are given of three other applications of the Poetsch system.

W. S. H.

Blasting in Fiery Mines. By H. Hervegh.

(Mémoires et Compte-rendu de la Société des Ingénieurs civils, vol. 1888, xli. p. 744.)

By means of diagrams, the Author describes an instrument, invented by Colonel J. Lauer, of the Austrian Engineers, in which the ignition of shots is effected by means of friction. The friction apparatus is enclosed in a small cylinder, and is attached to an iron wire, which, together with its encasing tube, projects slightly out of the bore-hole. It is terminated by a loop, which, as a precaution, is bent down and fastened to the tube by a thread. In the lower portion of the small cylinder, a detonating-cap is placed. The bore-hole is charged in the usual manner. The loop is then separated from the tube and straightened, and the wire is sharply pulled by means of a cord attached to the loop. In this way the composition contained in the cylinder is caused to ignite, and this explodes the detonator and the charge. By means of an arrangement of cords and rings, as many as eight shots may be fired simultaneously. This system of firing has been adopted in several Austrian collieries with satisfactory results.

B. H. B.

Compressed Air at the Blanzy Mines.

By F. MATHET, Engineer-in-chief.

(Bulletin de la Société de l'Industrie Minérale, 1888, vol. ii. p. 65.)

After a few notes of a historical character, the Author divides his subject into four sections, the first being devoted to a description of the various compressors used at Blanzy, of which there are three at the Sainte Eugénie pit; one on the Sommeiller principle (since replaced by one on the Hanarte system), with a pair of steam cylinders $19\frac{11}{16}$ inches in diameter, coupled direct to a pair of air-cylinders $17\frac{3}{4}$ inches in diameter, with a stroke of 3 feet $11\frac{1}{4}$ inches, making 16 revolutions, and delivering 110 cubic feet per minute; one on the Révollier system (altered and modified at the company's own workshops, by the introduction of Giffard's pistons and Colladon guided-valves, &c.), with Meyer valve-gear, having two steam-cylinders $25\frac{1}{2}$ inches in diameter, and two air-cylinders $21\frac{5}{8}$ inches in diameter, with a stroke of 5 feet 3 inches, making 20 to 22 revolutions, and delivering 229 cubic feet per minute; and one on the Dubois-François system, with two steam cylinders $21\frac{5}{8}$ inches in diameter, and two air-cylinders $19\frac{3}{4}$ inches in diameter, with a stroke of 2 feet $7\frac{1}{2}$ inches, making 25 revolutions, and delivering 117 cubic feet per minute, the pressure of air in each case being 64 lbs. per square inch. The receivers are formed of old boilers of various sizes, tarred within and without, with a total capacity of about seven times the volume supplied per minute. Near the mouth of each shaft the compressed air is passed through a smaller receiver, which is heated by the exhaust-steam.

At the Magny pit is a Révollier compressor, modified as above described, the receivers having a capacity of about eight times the volume supplied per minute.

The second section of the Paper treats of the distribution of the air by means of cast-iron pipes, with branch-connections of 5-ply canvas and rubber hose where required, and gives full dimensions and particulars of the pipes, joints, expansion-joints, methods of fixing, minor appliances and fittings, and of the loss of pressure owing to leakage, friction, &c.

The third section describes the machinery driven by the compressed air, consisting of (*a*) drills and jumpers; (*b*) coal-cutting machines; (*c*) hauling-engines and apparatus; (*d*) portable and subsidiary ventilators and blowers; and (*e*) pumps.

The fourth section is devoted to a summary of the general arrangement of the work, and of the actual results.

The Paper, of which the above bare summary is given, is very complete, extending to some ninety pages, and contains full particulars and tables of the work accomplished, with estimates of the cost as compared with hand-labour, and is illustrated by three large plates.

W. S. H.

Blast-Furnaces of Elliptical Section in the Ural. By C. FRÖLICH.

(Stahl und Eisen, 1889, p. 99.)

The Author has been engaged in smelting magnetic iron ore at Nischni Tagil in the Ural since 1867, and has developed several new forms of construction based upon the rectangular furnace of General Raschette. This, in its original form, having an oblong rectangular hearth with rounded ends, was very weak structurally, and the stack collapsed at periods between three and six months; the height, 20 to 34 feet, was insufficient for the refractory nature of the ore, a magnetite averaging 66 per cent. of iron, which arrived at the tuyeres in an almost unchanged condition, causing great corrosion of the hearth, which was formed of a rammed mass of clay and quartz. The blast-pressure of 2·5 centimetres of mercury, supposed to be sufficient, proved to be far too low, and, in some instances, a pressure of 17·5 centimetres was requisite in actual work. With all these disadvantages, however, the results obtained were not below those of the older circular furnaces, and although the experimental Raschette furnaces were completely destroyed by three to four years' working, the Author was so convinced of the suitability of the system to the locality, owing to the better distribution of the blast, that one was reconstructed of an elliptical section at Wiemo-Schaitanka in 1866, which, starting with a consumption of 101·8 of charcoal to the 100 of pig-iron made, reduced the amount in the most favourable period, February 1874, to 73·7 per cent., with a make of 24 tons daily from an ore yielding 66 per cent., while the best result with a circular hearth was 93 per cent. of the iron smelted. In consequence of this, the five then existing circular furnaces were changed to the elliptical form, and six new ones of the latter kind have since been built.

Although these furnaces were satisfactory as regards durability, the first having retained its lining for three years, while the outer stack and pillars had a life of more than fifteen years, the Author desired to try the experiment of dispensing entirely with the heavy and expensive casing-walls usual in old furnaces. This was considered to be rather hazardous in a country having a range of temperature from 110° to −40° Fahrenheit, and the first trial was made in an old Raschette furnace by removing the casing from the stack and leaving the hearth as free as possible. This went into blast in May 1875, and made 15 tons daily with a consumption of charcoal of 94·9 per cent., while in the older form, making 17 to 19 tons, the consumption of coke was 101·4 to 110 per cent.

In consequence of these results, the Nischni Tagil No. 3 furnace, having twelve tuyeres, was built in 1874–75, and Nos. 2 and 3 at Nische Salda, with eight tuyeres, in 1875–79. These latter are illustrated by plates. They have entirely free-standing stacks, boshes and hearths, the latter being strongly cooled by water-boxes. The dimensions range from 45 to 50 feet

height, 9½ to 15 feet length, and 2 to 3 feet breadth of hearth, and the capacity from 4,000 to 6,500 cubic feet. The gases are taken off by a cylinder hung in the throat, and the stack is braced by hoops, which bear against struts projecting from the middle of the long sides. The cost varied from 17,000 to 19,000 roubles (paper). No. 3 furnace at Nischni Tagil is the largest charcoal furnace in Russia, averaging from 20 to 28 tons per day, and has made as much as 49 tons when supplied with birchwood charcoal. The other kinds of charcoal are those of aspen, pine and spruce, the weights being as follow :—

1. Birch	195 to 205	kilograms per cubic metre.
2. Pine	140 „ 145	„ „
3. Spruce	120 „ 125	„ „
4. Mixed	140 „ 145	„ „

The charcoals deteriorate very much by keeping; that freshly made from birchwood, for example, increases 50 per cent. in weight by absorption of water from the atmosphere. The smelting is done with cold blast without flux when making white iron, and with blast heated to from 60° to 300° Centigrade, and a small addition of lime and sand, about 10 per cent. of the ore burden, when on grey or Bessemer qualities. Subsequently, in 1886–88, Cowper stoves, giving a temperature of 540° Centigrade, have been added at Nischni Salda to three furnaces making Bessemer metal, which is mostly transferred to the Siemens furnace to be re-heated for blowing, and is only cast into pigs when the steel-works are standing. The make is from 17·6 to 19·3 tons per day from 66 to 67 per cent. ore, the charcoal used being 104 to 113 per cent. Speaking generally, heating the blast results in a saving of 12 to 15 per cent. of fuel.

Another modification of the blast-furnace introduced by the Author is that of a shifting hearth which has been added to those, both of circular and elliptical section, illustrations of both forms being given. In these the hearth-bottom and lower part of the boshes up to the level of the base-ring of the stack are carried upon a cast-iron plate supported by screw-jacks which press it up against the stack-lining. When the hearth is burnt out, it can be removed by loosening the screws, which lower it on to a truck upon rails in a pit below; the new hearth, previously heated and filled with coals, is then brought into place and screwed up, the joint being made by a packing of fireclay, placed on the top-edge. The whole time required to replace the hearth is only twelve hours. The first of these furnaces was made for smelting ferro-manganese from an ore of the following composition :—

Silica	15·90
Alumina	7·30
Ferric oxide	17·40
Red manganese-oxide (Mn_3O_4)	58·43
Lime	0·57
Magnesia	0·35

The average make of 70 to 80 per cent. ferro-manganese from this ore was 2·4 tons per day, with a consumption of 4 to 5 times that weight of charcoal, with a yield of 42·7 per cent. on the ore, or 36·8 per cent. on the total burden. When on grey iron the make was 13¾ tons from 66·8 per cent. ore with a fuel consumption of 101 per cent. The working results of the elliptical furnace with shifting hearth are not given, but they are said to be very good, and the furnace itself was one of the chief attractions at the Ural Mining and Forest Exhibition held at Ekatherinburg in 1887.

H. B.

The Removal of a Blast-Furnace Bear by Dynamite.

By H. Münch.

(Oesterreichische Zeitschrift für Berg- und Hüttenwesens, 1889, p. 16.)

In a Paper on the breaking up of large masses of iron and steel by dynamite, the Author mentions an interesting application of the method to the removal of an obstruction from the hearth of a blast-furnace at Schwechat, near Vienna. This was of large dimensions; the upper cylindrical part, 2·65 metres in diameter and 2·15 metres thick, consisting of an agglomerate of iron, slag, brick, and graphite, being totally worthless, was first removed by boring six horizontal holes, 26 millimetres in diameter and 820 millimetres deep, which were loaded and fired with gradually increasing charges in the following order:—

Nos. 1 to 6.	First charge	. . .	55	grams.
,,	Second ,,	. . .	88	,,
,,	Third ,,	. . .	154	,,
,,	Fourth ,,	. . .	187	,,
,,	Fifth ,,	. . .	198	,,

Or, in all, 3·5 kilograms No. 1 dynamite and twenty-seven electric fuses. At the third blast cracks appeared in the mass, which widened with subsequent firing until entire separation was effected.

The lower part of the mass, which was also cylindrical, 4 metres in diameter and 700 millimetres thick, consisted of strong and tough cast iron. Nineteen vertical holes were bored into it, 28 millimetres broad and 350 millimetres deep. Twelve of these, forming an outer ring, were first loaded and fired until cracks appeared, when the inner ones were brought into action. After the sixth blast the mass was broken into two unequal parts, up to which time eighty-nine shots, requiring 9 kilograms of dynamite, were used. Subsequently a further quantity of 20 kilograms, and the boring of a few more holes, were required to reduce the fragments to manageable dimensions. The total consumption of materials for the second part of the work was:—Dynamite, 29 kilograms; one hundred and thirty electric fuses, thirty-two detonators,

and four coils of safety fuse, the total cost for material and labour being about £30. The second mass yielded 67½ tons of good cast-iron, suitable for re-melting, which was therefore recovered at a cost of about 9*s.* per ton for blasting, the furnace being in no way damaged by the operation.

At the Ternitz steel works three masses of cast iron, two weighing 1½ ton each, and the third 6 tons, and two Bessemer steel blocks of 1¼ ton and 4 tons weight, were similarly broken up by the use of dynamite. The requisite work and material per cwt. of metal broken being—

	Millimetres.		Grams.	
For cast-iron . . .	14·6	depth of borehole;	10·5	dynamite.
„ steel	13·5	„ „	81·5	„

A cast-iron howitzer, weighing 18 cwt., was broken by 6·16 kilograms by the Austrian Military Engineers at Ofen. This corresponds to 34·2 grams per cwt. of metal.

Heavy guns, and similar tubular masses of cast-iron and steel, may be safely and easily broken up by dynamite and water tamping. The charges required are based upon a standard of 100 grams of dynamite per centimetre in diameter of the bore, or the same quantity per cwt. of metal.

In 1876 a bronze breech-loading gun, weighing 14,169 kilograms, of 209 millimetres calibre, and 4·425 metres long, was destroyed by dynamite at the artillery trial-ground at Felixdorf, near Vienna. At first a charge of 6 kilograms of dynamite, distributed along 3·6 inches of the bore, was used, the tube being filled with water. This produced only a few small cracks, extending for about 30 centimetres. A second charge of 27 kilograms opened the crack to about 5 millimetres, and the tube was only broken by a third charge of 94·5 kilograms. This appeared to have been the proper quantity to use, and would probably have sufficed if used at first with water tamping. It corresponds to 334 grams per cwt. of bronze, or 4·5 kilograms per centimetre of the bore of the tube.

H. B.

The Basic Open-Hearth Process at Gratz. By F. Moro.

(Stahl und Eisen, 1889, p. 1.)

The ironworks at the South Austrian Railway station at Gratz, started in 1861 as a puddling-forge and rail-rolling mill, was changed to the Bessemer process in 1864, and in 1870 the first open-hearth furnace was added. After this time the two processes were carried on simultaneously till 1878, when the converters were removed, as the open-hearth method proved to be the only one fit for dealing with the large quantity of old materials sent in for re-manufacture. In 1885 three 12-ton furnaces with siliceous linings were in use, having gas- and air-ports side by side, and

horizontal regenerators; the charge consisted of 26 to 30 per cent. of grey pig-iron, and the remainder of old rails, &c., which was introduced at intervals of three hours, in three successive portions, having been previously heated. The operation lasted twelve hours; the loss of weight was 5 per cent., and the coal-consumption (lignite of 5,600 units heating power) 47 per cent.; the output being 14 cwt. of steel for each man employed in the shift.

The increasing scarcity of good scrap, however, led to the necessity of introducing a new method of working, in order to keep down the phosphorus in the ingots. For this purpose it was at first intended to use the Rollet process, as practised at Firminy, where the charge is introduced into the Siemens furnace in a melted state, but the Author found that the saving of fuel by this method does not compensate for the retardation of the fining; and although the product is of great purity, it was too costly a process for rail-making. It was therefore decided to introduce the basic process, for which purpose the works have been entirely rebuilt since 1886. Three new furnaces, taking 12-ton charges, are now in use. They have Hackney arrangements for the gas- and air-ports, upright regenerators, and are lined at the bottom and side-walls with rammed magnesite, the remaining parts being of the best Dinas bricks. A neutral packing of chromic-iron ore was at first used between the magnesite and the siliceous brickwork, but this has been abandoned as unnecessary. The roof only lasts for one hundred and fifty heats, while the ports and the fronts of the furnace endure from three hundred and fifty to four hundred heats. The duration of the heat is from five to five and a half hours, the longer time being required as the ports melt away, and the regenerators become blocked with the increasing age of the furnace.

The charge per ton of ingots for rails is:—

260	kilograms	White pig-iron.
740	,,	Old malleable iron.
40	,,	Spiegel; 12 per cent. manganese.
10	,,	Ferro-manganese and silicate.
1,050	,,	Total, including waste.

The proportion between the malleable scrap and pig-iron is a matter of indifference, on account of a modification of the process due to the engineer of the works, Mr. Pszczolka (not described by the Author), whereby the use of cast-iron is reduced to a very small quantity, and even has, in some cases, been entirely dispensed with.

The basic process has been found, under the above conditions, to be attended with great advantages. The cost of repairs and maintenance of the furnaces are about 50 per cent. higher than in the older method, but white iron can be used instead of grey for the initial bath, with a saving of cost in the proportion of 38 to 45, and the fuel-consumption in the producers is reduced from

47 to 30 per cent. of the weight of the charge, the loss in melting, 5 per cent., remaining as before. The output is now 1·24 ton per hand employed in the shift of twelve hours.

The quality of the steel is decidedly improved, as the ingots stand heat better, and bear a heavier pressure in the rolling-mill, which allows a more rapid system of rolling to be used. For this purpose the old system of cutting the ingots into single rail-lengths, and rolling upon a three-high mill, with an intermediate heat, has been abandoned, and a new reversing-mill and engine has been erected. The latter, which is from the designs of Professor Riedler, is noticed at some length, with illustrations of some of the details. Some of the contrivances, such as that for ensuring complete separation of water from the steam, are of interest, and the driving pinion-standards are on the engine-bed frame. The use of a loose coupling spindle between the pinions and the engine being thus dispensed with, a more uniform wear on the pinions is produced than is possible with the older arrangements.

The rail-mill has two pairs of rolls, each 1,800 millimetres long and 710 millimetres in diameter, each having six grooves. The ingots, 310 millimetres by 270 millimetres in section, weighing 880 kilograms for three, and 1,150 kilograms for five rail-lengths, are heated in two heating-furnaces placed at right-angles to the mill, and make twenty-four passes, of which eighteen are in the roughing-rolls, which have the top roll counterbalanced like that in a plate-mill. The finishing-grooves are on the side nearest to the engine, whereby the furnaces are kept as far from the engines as possible, while the delivery takes place immediately in front of the saw. The mill is only at work during the day-shift, which leads to some loss of fuel in keeping the furnaces heated at night; but notwithstanding this, a considerable economy has resulted from the new arrangement, as is shown in the following comparative statement:—

——	Old plan. Single-rail Lengths.	New plan. Three-rail Lengths.
	Tons.	Tons.
Rails produced in twelve hours	50	100–110
Per mill-hand	3	12
	Kilograms.	Kilograms.
Ingots charged per ton	1,220	1,120
Crop ends and waste	170	92
Loss in heating	50	28
Furnace coal (3,700 calorics), including night heating, per ton of rails	480	410
Engine coal (4,100 calories), including night heating	530	320

Of the total amount of coal used, 80 kilograms are required for the heating furnaces, and 50 kilograms for the boilers at night; together about one-seventh of the total which is lost by working single shifts only.

At most two-thirds of the ingots are introduced hot from the moulds into the heating-furnaces; and it is found that, for the best work in the mill, they should not remain less than four hours in the furnace, which, taken together with the lower calorific value of the coal, accounts for the large consumption in re-heating.

The capacity of the mill is about 150 tons per shift; the smaller amount of 100 to 110 tons being the limit of the two heating-furnaces in use.

Steel from this process has been rolled into armour-plates for forts, which showed great toughness and high resisting powers to shot when tested at Felixdorf, near Vienna, in the summer of 1888.

The production of steel castings from the basic furnace was at first attended with difficulty, as, owing to the high oxidizing energy in the furnace, it was not possible to bring back the carbon to a higher point than 0·4 per cent. This has been got over by making the addition of spiegel in the ladle, and sound castings of any desired hardness are now easily produced.

H. B.

On Nitrogen in Bessemer- and Open-Hearth Steel.

By H. Tholander.

(Jernkontorets Annaler. 1888, p. 429.)

The generally received belief that open-hearth steel is preferable to that made by the Bessemer process, in regard to softness and toughness, may, in the Author's opinion, be due to differences in the proportion of nitrogen present in the two classes of metal. In the Bessemer process, nitrogen is brought into intimate contact with the charge, by reason of the great volume of blast sent through; whereas in the Siemens process the contact between air and metal is only superficial, and the latter is very generally protected with a coating of slag. As this point has not hitherto been investigated, a considerable series of nitrogen determinations have been made with the view of proving the hypothesis stated above. The method adopted, as being best suited for iron-works laboratories, was that of Boussingault, in which nitride of iron is decomposed by solution in sulphuric acid, with the formation of an equivalent of ammonium sulphate. The ammonia is driven out of the sulphate by the action of sodium hydrate, and collected and determined by some volumetric process, and from the result the proportion of original nitrogen in the metal is computed.

Great care is necessary to obtain reagents free from nitrogen, especially distilled water, sulphuric acid, and caustic soda lye, and the precautions necessary to be observed in their production are given at length; they consist mainly in very careful distillation of the different liquids.

The quantity of metal operated upon was 5 grams, which was

dissolved in a boiling mixture of 8 cubic centimetres of sulphuric acid and 60 of water; and to the solution, diluted to twice its volume when cooled, 40 cubic centimetres of caustic soda solution (270 grams to 1,000 of water) were added. This was subjected to distillation in a long-necked flask, the ammonia being received in a measured volume (10 cubic centimetres) of 5 per cent. standard sulphuric acid liquor. When the distillation was complete, the excess of unsaturated acid was determined by adding a fragment of iodide of potassium, or a small quantity of 4 per cent. potassium iodate solution, the iodine set free being finally determined by a 5 per cent. standard solution of sodium hyposulphite. Each cubic centimetre of the latter less than 10 corresponds to 0·0007 gram, or 0·014 per cent. of nitrogen in the sample, and as the volume of the solution may be measured accurately to $\frac{1}{20}$ cubic centimetre, the results obtained may be considered as correct to within about 0·001 per cent.

The materials investigated were Avesta Bessemer iron, open-hearth steel from Hammarby, Finspong and Avesta, the first from the ore process, and the other two from the scrap process, and crucible steel from Wikmanshytta. Some experiments were also made with case-hardened soft iron. The general results are summarised as follows:—

Ordinary Avesta Bessemer iron contains 0·012 to 0·022 per cent. of nitrogen, but by overblowing three minutes it may be increased to 0·032 per cent

Hammarby soft open-hearth iron, ore process .	0·005 to 0·006 per cent.
Finspong ,, ,, scrap ,,	0·005 ,, 0·008 ,,
Avesta ,, ,, ,, ,,	0·008 ,, 0·013 ,,
Wikmanshytta crucible steel, soft . . .	0·006 ,, 0·008 ,,

Strips of soft Siemens steel (0·10 C) sheets, when hardened by immersion in a bath of melted cyanide of potassium for variable periods up to half an hour, contained 0·297 per cent. of nitrogen as a maximum. This was so hard that it scratched glass with ease. Bessemer soft iron similarly treated contained 0·310 per cent.

The difference in quality between soft steel plates made in Sweden by the Bessemer and Siemens processes, is not, as a rule, appreciable by the hardening test alone, as plates made by the former process, though passing this test perfectly, are often rejected as hard and brittle in use. There is, however, a great difference in their behaviour when the plates, after punching and shearing, are subjected to bending without previously removing the burrs from the holes and sheared surfaces. Siemens sheets may be treated in this way without harm, but those from the Bessemer process very frequently crack on the edges in the bending, or shortly after, the effect being most marked when the burrs are bent outwards. When, however, the plates are trimmed and annealed after punching and shearing, there is not much difference between them. The colour of a sheared Bessemer sheet is brighter and more silvery than that of an open-hearth one, which approaches to lead-grey; and this

difference is perceptible even when the composition, as determined by analysis, is practically the same.

The Author considers that much of the evil effect of over-blowing, and which is usually attributed to oxidation, is actually due to nitrogen, which is taken up during the over-blow, as the metal is then practically in a nitrogen atmosphere, the oxygen being fixed by the burning of the iron. He therefore thinks it of importance, in the production of soft Bessemer metal, to work with cast-iron as free as possible from substances other than carbon—manganese being especially prejudicial in this respect, as tending to lengthen the process from its great affinity for carbon. This is seen in the Mitis process, for which an iron with 0·1 per cent. of manganese is better than one with 0·4 per cent., as the latter has a greater tendency to take up carbon from the black-lead crucible, and so produces harder castings than the former. For the same reason, a Bessemer pig with 0·4 per cent. of manganese is to be preferred to one with 0·8 per cent., even though a large quantity of ferro-manganese may be required in the final tempering of the product.

The following conditions are given as desirable for the production of Siemens metal of the toughest and softest qualities:—

1. Pig-iron as free from nitrogen as possible; charcoal-iron, produced with a moderate temperature on the hearth, being preferable. The refining should be done with pure and rich ores.

2. The heating should be done with producer-gas from wood, or preferably, with water-gas.

3. The blast-furnaces to be so arranged that there is as little contact as possible with the charge.

4. A neutral lining is probably the best, if it can only be made sufficiently durable, but on this point there appears to be a considerable difference of opinion at the present time. The neutral process requires a minimum of silicon and nitrogen in the metal, or, as regards the latter, directly the opposite of the basic process.

H. B.

On the Nature of the Welding of Iron and Nickel.

By T. FLEITMANN.

(Stahl und Eisen, 1889, p. 9.)

In the Author's process of plating iron with nickel, by pressure between rolls at a welding heat, the nickel is recovered from the clippings and shearings of the plates by the action of dilute sulphuric acid at a temperature of 50 to 60° Centigrade, which dissolves the iron core, leaving the nickel in the form of thin metallic slips, only from 2 to 3 per cent. at most of the latter metal being dissolved. The operation is concluded when the evolution of hydrogen ceases. Even a further action with fresh acid has but little effect, supposing that an increase of temperature is

prevented. The plan of separation of the two metals is apparently perfectly defined.

When, however, the residual nickel is examined chemically, it is found to differ from its original composition, the amount of iron present being notably increased. For example, in a nickel containing originally only 0·9 per cent. of iron, 2 per cent. more was found when it was recovered from the plate-cuttings; and even by a long-continued treatment with dilute acid, the iron could not be sensibly reduced. This peculiar behaviour pointed to the possibility of actual chemical combination taking place between the metals, and that alloys of iron and nickel were produced in the welding, as it is well known that iron, with even a small proportion of nickel, resists the action of acids better than the pure metal.

In order to test the point further, the residue from a weighed quantity (20 grams) of the clippings, after the removal of the iron, was subjected to fractional solution in aqua regia, the weight of metal dissolved in each operation being determined by weighing the residue after carefully washing and drying it, the surfaces of the clippings being rubbed on a cloth in order to remove any adherent insoluble carbon and iron compounds. The results obtained in six operations were as follow :—

——	Weight Dissolved.	Proportion.	Iron per Cent. in Nickel.
	Grams.	Per cent.	
I.	1·569	7·84	5·31
II.	1·711	8·55	3·99
III.	1·715	8·58	2·44
IV.	2·019	10·09	1·53
V.	1·896	9·48	1·00
VI.	0·919	4·59	0·89
	9·829	49·13	

This experiment shows the molecular interpenetration of the two metals to be such that 45 per cent. of the nickel-coating had to be dissolved before it was obtained of its original composition. The cause of this very considerable change taking place in two metals, at a temperature from 500° to 600° below their melting points, has been a puzzle to the Author, who has hitherto refrained from publishing these experiments, which were made several years since; but latterly a new phenomenon, which has been observed in annealing nickel-plated sheets at the Westphalian Nickel Rolling-Mills at Schwerte, leads him to believe that it is to be attributed to an actual volatilization of the iron atoms. This has been proved by exposing sheets of iron and nickel, laid loosely together, to a red heat for a considerable period, when it is found that the iron distils over in notable quantity to the nickel sheets, where it forms

a surface covering, without any welding, or even adhesion of the two metals taking place. The result is the formation of a true alloy over the entire surface of the nickel plate, which penetrates to a depth of $\frac{1}{20}$ millimetre in sheets of 1 millimetre thick. This contains, as a whole, about 24 per cent. of iron, and as much as 50 per cent. in the outside part. The determination of the penetration was made by fractional solution, in the same manner as previously recorded. In one case a plate of nickel containing 1·1 per cent. of iron, weighing 16·1395 grams, that had with similar plates been exposed in alternation with iron slabs 6 millimetres thick for sixty-four hours to a red heat, gave the following results:—

——	Weight dissolved.	Iron in Solution.	Percentage of Iron in Solution.
	Grams.	Grams.	Per cent.
I.	0·595	0·3236	54·4
II.	0·300	0·0546	18·2
III.	0·792	0·0209	2·7
IV.	5·914	0·0620	1·05
V.	1·653	0·0193	1·16

It might have been supposed that the formation of the alloy would have been common to the surfaces of the two metals; but this is not the case, as in no instance was the iron found to contain nickel beyond the amount ordinarily present in commercial iron, say $\frac{1}{10}$ per cent. of nickel and cobalt together. The molecular mobility seems therefore to be confined to the iron atoms alone. The surfaces of the iron plates, after the experiment, showed no change except that ordinarily produced by annealing; while those of nickel appeared nearly silvery white, or the colour of a 50 per cent. iron nickel alloy, and after scouring and polishing through rolls, the coating had a velvety appearance, like that of a nickel or silver coating electrolytically deposited.

The increase of weight of a series of nickel plates from the formation of the surface alloy, when heated between iron plates, has been determined by weighing. The experiment lasted sixty hours:—

Nickel Plate.	Before Heating.	After Heating.	Increase.
No. 1	16·025	16·280	0·255
„ 2	15·960	16·290	0·330
„ 3	15·895	16·230	0·335
„ 4	15·935	16·340	0·405
„ 5	15·998	16·340	0·342
„ 6	15·780	16·130	0·350
„ 7	15·780	16·150	0·370
„ 8	15·920	16·310	0·390
„ 9	15·925	16·270	0·345

The increase is nearly the same in all cases except No. 1, which is explained by the fact that there only one surface was in contact with the iron plate, the other one being free; but even on the free side some iron was taken up, as both sides were similarly frosted in appearance.

Under what conditions volatility is set up in the iron is, according to the Author, still to be determined. It may be simply a consequence of direct distillation; or some foreign body, such as cyanogen, chlorine, or a volatile chloride, when present, may act as a carrier. In any case, he considers that the intimate union obtained between the nickel and iron, and even that between two masses of iron, is due to the volatility of the latter metal at a heat far below its melting point.

The Paper concludes with a series of propositions on the conditions necessary to obtain perfect welding, which may be summarised as follows:—

1. The most important and indispensable is perfect metallic contact of the two surfaces.

2. Easy welding supposes a considerable difference of temperature between the point of fusion and that of plastic softness.

3. The prejudicial effect of combined and alloyed foreign substances is due to their action in either diminishing the softness, or sensibly lowering the melting point, of the metal. The welding capability of nickel is largely increased by an addition of magnesium, which removes combined oxygen and carbonic oxide, thereby raising the melting point about 100°.

4. Soft steel is notably less easily welded than welded iron. This is due to the more intimate union of the foreign matters, carbon, oxygen, silicon, phosphorus, &c., in the former than in the latter metal. In order, therefore, to obtain ingot iron of good welding character, efforts should be directed to raising its melting point and plasticity by the removal of these foreign matters. The presence of cinder in puddled and hearth finery iron has no effect upon the welding power of the metal as such.

5. The so-called welding mediums serve either to clean the surfaces, or prevent their oxidation when heated, and are of no further utility. They may be entirely dispensed with when the surfaces are clean, and other methods are adopted to exclude air.

H. B.

On a Furnace for Calcining Magnesite. By J. von EHRENWERTH.

(Oesterreichische Zeitschrift für Berg- und Huttenwesens, 1889, p. 102.)

In the preparation of magnesite for use in the basic-steel furnace, it is necessary not merely to drive off the carbonic acid, but to expose it to a strong white heat, in order to shrink it to a maximum, the contraction upon the original volume being nearly 50 per cent. The use of kilns for this purpose is attended with some

disadvantages, as the material, when strongly heated, breaks up into splinters, and, from its lower thermal conductivity, it is difficult to burn lumps of large size completely through; also on account of the very high temperature required, the operation of drawing the kiln is very heavy and troublesome. The Author, having been informed by Mr. G. Götz, of Pittsburg, that he had found the Siemens furnace to be the best kind for the purpose, has designed a combination of a reverberatory furnace with a kiln fired by gas, in which the two operations of causticizing and dead-burning are separated. The furnace, which is illustrated by two figures, but without dimensions, consists of a reverberatory calciner of oblong shape, with three doors on each side and a slightly domed roof. It has a rectangular vertical shaft at the firing end, below the level of the bed, and a larger one at the flue end, in the position of the stack in an ordinary reverberatory furnace. The latter forms the kiln in which the raw stone is charged, and is heated by the current of waste gas, up to the point where it begins to splinter. It is then raked on to the horizontal bed and broken up, so as to bring it into intimate contact with the flame, and traversed slowly to the firing end, where it falls into the lower shaft, and is allowed to cool before drawing. The firing is effected by producer-gas, introduced through a series of vertical burners in the roof above the lower shaft. The air for combustion is introduced through a series of openings at the bottom of the latter, and becomes strongly heated before it meets the gas, by traversing the finished charge which is awaiting removal. The cost of a furnace of this kind, capable of producing 5 tons of dead-burnt magnesite daily is, in Styria, from £500 to £700, including gas-producer and chimney-stack.

H. B.

The Russell Process in Utah.

(Park City (Utah) Record, Dec. 29, 1888.)

At the Marsac Mill, a plant capable of treating 120 tons of ore daily by the Russell process has recently been put in operation. It consists of four ore-vats, 17 feet in diameter and 8½ feet deep, of a capacity of 65 tons each, eight precipitating tanks 10 feet in diameter and 2 feet deep, three storage tanks, small in size to the latter, and four rectangular sumps, 17½ feet by 2¾ to 3¾ feet deep and 3½ to 8½ feet broad. Two of the precipitating tanks are used in the separation of lead, four for the bulk of the gold and silver, and two for saving silver from the wash-water.

The first part of the treatment is similar to that in amalgamation, except that the ore is not so finely crushed, a screen of 10 holes to the inch instead of 40 being used, less salt is added, and the roasting, which is done in a Stetefeld furnace, is more rapidly effected. When cooled, the roasted ore is charged into the vats, and

jected to a preliminary washing with water, to remove soluble salts that would otherwise contaminate the hyposulphite liquids. Any silver salt in the wash-water is precipitated in the tanks by sodium sulphide. The "stock" solution of sodium hyposulphite is then used for dissolving the gold and silver compounds in the ore, and is followed by the "extra" solution (made by adding a certain amount of copper sulphate to the stock solution). It is immaterial whether the copper compound is added to the ore during the working with alkaline hyposulphite, or in some other solution. The copper is first precipitated by carbonates, if any are present in the ore, but dissolves in the excess of hyposulphite forming the extra solution. The action of the solutions is continued for several hours, until all the soluble gold and silver compounds are taken up, when the liquids are run off to the precipitating tanks, and the exhausted ore is washed by a water-jet out of the vat which is then re-charged for a fresh operation.

The extraction-liquors are first subjected to the action of sodium carbonate in tanks Nos. 1 and 2 to remove lead, which goes down in a white powder that settles quickly; the clear solution is removed to the tanks Nos. 3 to 6, where the gold, silver and copper are thrown down by sodium sulphide. When the precipitates have settled, the clear solution of sodium hyposulphite is drawn into a sump, whence it is lifted by a centrifugal pump into a storage tank placed above the ore-vats. About twice a week, the sulphide-precipitates are drawn into the proper sumps. Nos. 1, 2 and 4 are connected by pipes to a pressure-tank, whence the precipitates are forced by a pressure of 80 lbs. to the square inch into a Johnson filter-press, which removes about 40 per cent. of the adherent moisture, the remaining 50 per cent. being expelled by heating in a furnace before shipment. The product is then ready for shipment to smelting works at a distance, or for further treatment on the spot. The sodium carbonate and sulphide solutions are prepared in cast-iron tanks, 7 feet in diameter and 3 feet deep, and are stored in wrought-iron tanks, 7 feet deep by 3½ feet in diameter. The quantities of chemicals used per ton of ore are—

Sodium hyposulphite	1½ lb.
,, carbonate	6 lbs.
Sodium hydrate (caustic)	5 ,,
Sulphur	3⅓ ,,
Copper sulphate	5 ,,

costing 2*s*. 3*d*. at New York or San Francisco, and 3*s*. 6*d*. on the spot. The cost of the plant is about £4,000.

The advantages claimed for this process over amalgamation are numerous. The pan amalgamation plant at the same works, having a capacity of 65 tons daily, has twenty-seven pans, settlers, agitators and a clean-up pan, while the extraction vats, tanks and sumps per 120 tons are only twenty-one in all. The castings in the former weigh in all 371,000 lbs., while the total weight of iron, both cast and wrought, in the latter is only 27,000 lbs. The

capacity of the battery is nearly doubled owing to the coarser screens used, and the roasting need not be so complete as in amalgamation. The chemicals used represent only $\frac{1}{150}$ part of the cost of the mercury in circulation in the pan-room. The charges are thirty times larger than those of the amalgamation pan, and only one-fiftieth of the power and one-sixth of the water are required. The proportion of silver extracted is 2 per cent., and that of gold, 40 per cent. more than in amalgamation, while the cost is about 30 per cent. less

In a series of experiments at the Ontario Mill, great improvements have been made in the application of this process, particularly to ore containing gold and silver when roasted in a Stetefeld furnace without salt. With an addition of 8 per cent. of salt, the proportion of silver recovered was 91·9 per cent., and on ore roasted without salt 85 per cent.

H. B.

Electric Energy from Carbon without Heat. WILLARD E. CASE.

(Transactions of the American Institute of Electrical Engineers, 1888, p. 195.)

The second law of thermodynamics states that when mechanical energy is obtained from a hot body by cooling it, a fraction $\frac{t}{T}$, where T is the higher, and t the lower temperature[1] on the absolute scale of the total heat, is transferred. If the energy of carbon could be converted electrically into mechanical energy, without first converting it into heat energy, this fraction of the energy would be utilized.

Jablochkoff has constructed an electric-battery having plates of iron and carbon immersed in fused potassium nitrate (nitre), the carbon is oxidized to CO_2. There is strong local action in the battery.

The Author has experimented on plates of platinum and carbon in sulphuric acid (sp. gr. 1·81, temperature 75° Fahrenheit), in which potassium chlorate is dissolved, with the following results.

The electromotive force varied with the quality of carbon used. With lump graphite it was 0·8 volt, with gas carbon, 0·5 volt. Carbon produced by the action of sulphuric acid on cane-sugar, 0·3 volt. Other forms: animal charcoal, wood charcoal, coke, gave 0·3 to 1·24 volt. Finely divided carbon in a porous cup gave 1·24, due apparently to the presence of the oxygen of the air. The chemical action appeared to be due to the action of chlorine peroxide on the carbon, the result being the formation of chlorine and carbonic acid. The experimental cell had an internal resistance of 2·7 ohms. The cell polarized rapidly when giving current.

Another form of cell, used experimentally by C. S. Bradley, consists of a carbon and platinum pair in a solution of manganate

[1] *Sic* in original.

of potassium, through which air is forced to reoxidize the salt as it is reduced by the carbon. Coal was the form of carbon tried. The electromotive force was nearly 1 volt. The resistance of the cell was very high.

LL. B. A.

Six Years' Practical Experience with the Edison Chemical (Electricity) Meter. By W. J. JENKS.

(The Electrical Engineer, New York, 1889, p. 7.)

This Paper, read before the American Institute of Electrical Engineers, commences with a detailed description of all the meters devised and patented by Mr. Edison, and which are deemed more or less practical and adapted for commercial requirements. The special subject is, however, the electrolytic meter, consisting of two glass cells containing zinc electrodes, immersed in a 10 per cent. solution of zinc sulphate. These cells, shunted by small German-silver resistances, are introduced in the main circuit, the resistances being adjusted so that one cell receives $\frac{1}{975}$ of the current, and the other one-third of that amount, one cell being adapted for a monthly account, and the other for a trimensual. In localities where the solution is likely to freeze, the precaution is adopted of introducing into the case containing the cells a thermostat and a glow-lamp, the circuit of the latter being closed by the former when the temperature falls below a certain minimum. The positive plates are removed once a month, and weighed, the loss since the previous weighing serving, by a simple calculation, to give the amount of current which has traversed the circuit controlled by that meter, and the consumer's account is made out accordingly.

The different objections which have been raised against electrolytic meters are discussed *seriatim*, and the principal of them are obviated by ordinary care in cleaning the plates, and the use of pure chemicals; these latter, it may be noted, are supplied from a specially-appointed bureau of the Edison companies. The effect of temperature, as well as the variation of the electrical quantities involved, are diagrammatically exhibited, from whence it appears that these variations may be neglected in commercial practice, the ultimate limit of error being less than 2 per cent.

Finally, the experience of the different subsidiary Edison companies has been obtained in answer to definite questions circulated among them for the purpose, and their replies are extremely satisfactory as to the reliability of this meter, as well as to the advantage for both supplier and consumer of adopting payment by meter, instead of by time contract.

F. J.

An Astatic Electrometer capable of serving as a Watt-Meter.

By R. BLONDLOT and P. CURIE.

(Comptes rendus de l'Académie des Sciences, vol. cvii., 1888, p. 864.)

This instrument, a modification of Sir W. Thomson's quadrant electrometer, consists of a suspended needle formed of a circular disk, divided along a diameter, and the two halves insulated from one another. This needle is very light, rigidity being obtained by slightly corrugating the surface. The fixed plates are also semicircles, and, provided that the angle between the two diametral separations is not very small, the deflections of the instrument are directly proportional to the product of the differences of potential existing between the halves of the movable and fixed plates, special advantage in this respect being claimed for the complete symmetry of the fixed and movable portions, as compared with the quadrant electrometer, where there is, in certain cases, a couple tending to bring the needle into the symmetrical position. The connections to the movable portions are naturally formed by the bifilar suspension. This instrument can be used in various ways. For example, by connecting one set of plates to the terminals of a source of electromotive force, and the other set of plates at the ends of a known resistance in the same circuit, the deflections will be proportional to the watts; and, in this way, the instrument is specially applicable to the determination of this quantity for alternating currents, owing to the absence of self-induction. If the upper and lower portions of the fixed plates be likewise separated from one another, the instrument can be used differentially.

F. J.

The Capillary Electrometer, and the Mercury-Drop Electrodes.

By JAMES MOSER.

(Comptes rendus de l'Académie des Sciences, vol. cviii. 1889, p. 231.)

From Lippmann's electro-capillary experiments, Helmholtz has drawn the conclusion that if an insulated mass of mercury be allowed to flow away rapidly in drops from the end of a funnel placed in the midst of an electrolyte, there will be no difference in potential between the latter and the mercury in the funnel. This theorem affords a method for determining the level of potential at different points of a voltaic cell, and the Author's observations show that the sum of the values for the difference between the component elements agrees exactly with the total value for the cell under experiment. He shows, further, that Ostwald's contradictory results arise simply from a misunderstanding of Lippmann's electro-capillary constant, which is a function of a total electromotive force, but made up of two parts, of which one

depends on a force exterior to that existing at the contact of the mercury with the acid. The Author's determination of the portion where the error arises accounts exactly for the values in Ostwald's results, which he obtained by altering his electrodes, in order to eliminate what he deemed some defect therein.

F. J.

Self-Registering Voltmeters and Amperemeters.

By J. LAFFARGUE.

(L'Electricien, 1889, p. 72.)

In electric-light stations readings of the volts and amperes are taken at certain hours only, but experience has shown that a continuous record of the indications of these instruments is essential. The registering principle has been successfully applied to the measuring apparatus of Javaux, Hummel, Hartmann-Braun, &c., which consume very little energy, and can therefore be kept in circuit. In the Paper there are some curves of results obtained by Mr. Brillouin with the instruments used at the central station in Pau. The kind of control that can be maintained is shown by two curves of potential; the one recorded by the instrument during the first few days of service is irregular, but as the disturbing influences were under constant supervision, they were soon so far modified that the curve assumed a more regular form, and indicated that the variations of potential had been reduced to a minimum.

J. J. W.

Universal Aperiodical Galvanometer. By Dr. A. D'ARSONVAL.

(La Lumière Electrique, 1889, p. 13.)

The various parts of this instrument are of such design as admits of the ready removal and replacement of any particular one. The mirror can be detached from the suspension fibre, as well as from the magnet on which the current acts. The damping arrangement can be altered at pleasure, without interfering with other accessories, and the coils removed and another set readily substituted.

Across the centre of the circular base of the galvanometer is fixed edgewise a graduated bar, carrying at each end a sliding stage, to which a circular bobbin, wound with insulated wire, is attached. The central, or zero mark, on the bar corresponds with the middle of the base. The inner face of each bobbin is hemispherical in contour, so that a hollow sphere is formed for the reception of the damping ball, whenever the two bobbins are in juxtaposition at the centre of the bar. A cylindrical mirror-box, surmounted by an upright metal tube for the directing magnet, is fixed at the bottom to a flanged disk, from the centre of which depends a short tube, terminating in a boss with a screw-thread

on the periphery. The damper, consisting either of a copper ball or a cylinder of special form, with internal sliding-ring, is screwed to this boss. The support for the mirror-box consists of two columns, to which is fixed a cross-piece, having the middle part turned out to form a conical fitting for the disk, the flange of which rests on the upper surface of the cross-piece. The top of the tube, which carries the directing magnet, is closed by a metal stopper fitted with a small upright bearing for a milled-head screw. On the latter is wound one end of the suspension fibre; at the other end is fastened a small hook that engages in an eye in the upper part of the mirror attachment, the lower part of which consists of a short piece of tube of minute bore. A wire, carrying at its lower end a powerful ⊓-shaped magnet of small dimensions, is slightly tapered at the top, so that it can be readily inserted in the tube. The spherical damper is bored out for the reception of the magnet. An astatic system, similar to Nobili's, and consisting of two of the small magnets, one at each end of the wire, can be substituted as occasion demands. The short wire coils have a resistance of $\frac{4}{10}$ ohm, whilst that of the long wire ones is 20,000 ohms. This galvanometer, which can be made aperiodical or ballistic at pleasure, is suitable for measuring temperatures, electromotive force, resistances, and current strength.

J. J. W.

A New Electrical Telemeter. By Dr. Paul Mönnich.

(Repertorium der Physik, 1888, p. 696.)

This instrument is of the type adapted for communicating to a distance the indications of physical instruments such as barometers, thermometers, &c., and its method of action is based on the principle of Professor Hughes' induction-balance. At the transmitting end, where the physical instrument, *e.g.*, a metallic thermometer, is situated, is arranged a system of two coils of wire, one being fixed, the other mounted on an axis passing through the central diameter of the other coil, and constrained to move through any given angle by being connected to the indicating lever of the thermometer. At the receiving end is an exactly similar system of coils, electrical connection between the two fixed and two movable coils being effected by two pairs of conductors. In the circuit of the fixed coils is inserted a battery and vibrating contact maker, while in that of the movable coils, which are joined up with opposing poles, is a telephonic receiver. When it is desired to take a reading of the thermometer, the vibrator is put in action, and the movable coil is turned until silence is obtained on the telephone; an indicator, fixed to the movable coil, and working over a properly divided scale, will then give the indications of the thermometer, as silence is obtained only when the angular distance between the fixed and movable coils is the same at both stations.

F. J.

A New System of Multiplex Telegraphy.

By Lieut. F. JARVIS PATTEN, U.S.A.

(The Electrical Engineer, New York, 1889, p. 85.)

If a telegraph-line be connected at its two ends to two identically similar distributors which are caused to rotate in unison, and at such a speed that one revolution of the distributing arm is made in less time than is required for a single signal from a hand-worked contact key; then, dependent on the electrical value of the line, a certain definite number of separate circuits may, at the two terminal stations, be fed by the one line, and without any interference between them. This is the basis of all multiplex systems; but the novelty here presented consists in the fact that the distributor at the further end of the line is constrained to work in unison with the one at the home station, even though the latter does not maintain a uniform rate of speed.

The distributor consists of a trailer, rubbing over a plate divided into a certain number of insulated segments; this trailer, rotated by a suitable magneto-electric motor, sends through the line one or more positive and negative currents alternately for each revolution; and these currents actuate a polarized relay at the distant end of the line, which in its turn closes the circuit of a similar magneto-electric motor actuating a similar distributor. The halves of the distributing plate on each side of a certain diameter will therefore receive, the one positive, the other negative currents; and if segments diametrically opposed be connected through a suitable key, the motion of this key will control the currents passing through its circuit, in which will be included the instrument connected at the other end of the line to the similarly situated pair of segments. Thus the synchronizing currents sent from the original controlling instrument are used for that purpose for only a certain portion of a revolution, and for the rest of the time are applied to working the telegraphic instruments.

The difficulty experienced with an ordinary two-pole motor, arising from its liability to reverse its direction of motion even at full speed, was overcome by connecting two ordinary Siemens H armatures at right-angles on the same axis, and it was found that this motor fell into exact step without any adjustment being required between the motor and the trailer. Different suggestive arrangements of the system are described, and illustrated with the necessary diagrams; and the adoption of a special form of relay with interlocking contacts is mentioned as one method, among others, of obviating the chattering of the relay tongue, which in ordinary polarised relays would result from the periodical interruption of the circuit caused by the movement of trailer.

F. J.

On Underground Conductors in Electric Installations.

By Dr. WERNER v. SIEMENS.

(Electrotechnische Zeitschrift, 1889, p. 177.)

This communication contains a complete refutation of Professor Forbes' statement before the Institute of Electrical Engineers, that lead cables as instanced by those laid in Berlin, Milan and Rome by the firm of Siemens and Halske, had a life of only three years. The Author suggests that this statement can have arisen only from some complete misunderstanding between Professor Forbes and his informants; the actual facts of the case affording quite the opposite conclusion, as out of a total length of 130 kilometres (80 statute miles), nearly half of which was laid in 1885, only 200 metres (220 yards), or less than $\frac{1}{6}$ per cent., have up to the present time required replacing. It has been suggested that an electro-chemical action will arise between the lead and the external hoop iron armouring, but the positions of lead and iron in the galvanic series militate against such an idea; and care is specially taken that no contact should exist between the two, which are separated by a thickness of 3 millimetres ($\frac{1}{8}$ inch) of jute impregnated with an asphalte compound. It is difficult to determine the nature of the faults that have been cut out, as the passage of the electric current has melted lead, iron and copper into one general mass at the places where the faults have occurred; and from the nature of the network of the conductors, it is impossible to detect the faults as they gradually develop, any small faults interfering in no way with the commercial working of the system; it is however most probable that all these faults are the consequence of some mechanical injury, the result of excavation by workmen in the neighbourhood of the cable. Lead cables are by no means an innovation of recent date; in the years 1847 to 1850 a considerable length of conductor, insulated with gutta percha and covered with lead to protect the core from the ravages of field animals, was laid down in Prussia for telegraphic purposes; and some of it exists to the present day in a perfect state of preservation, though it did not fulfil the required end, as it was found that the lead covering was not a safeguard from the attacks of rats and mice, etc. There is no doubt that in certain positions, where the soil is made up of decaying vegetable matter, the lead would be converted into the carbonate or acetate; though this could not be obviated by embedding the cable in lime or cement, still the asphaltic compound and jute would suffice for such protection. Should it be objected that the jute serving will in time afford such vegetable matter, even if it be for a long time protected by the asphaltic compound, the jute, if expense be neglected, could be replaced by asbestos; but the Author considers that for all practical and commercial purposes the compounded jute will be found to possess very lasting qualities. As the hoop-iron protection is meant to be a protection only against

ordinary mechanical injury, all working in the ground in the neighbourhood of the conductors should be carefully watched; and the position of the cable may also be protected by a covering of slate or stone slabs, or if underground conduits exist, the laying of the cables in them would be especially advantageous.

In Berlin the network of conductors is so interconnected that it is impossible to obtain electrical tests of the insulation of the conductors, but the electrical tests of ten cables of similar construction laid in Munich in 1884, and each about 1 statute mile long, give for nine of them a dielectric resistance per kilometer of 50 megohms, while one of them is considerably less; the resistance was originally 160 megohms, but the reduction here observed is ascribable to the fact that the ends of the cable were in a very damp position.

The Author concludes with the belief that, though it is quite possible a better cable may be devised for underground work in electric-light installations, still at the present time these lead cables hold the field, and very efficiently fulfil their purpose, as their employment in Berlin, Munich, Rome, Turin, Milan, Mulhausen, Elberfeld, Darmstadt, Geneva, Salsburg, Lyons, Haag, St. Petersburg, Moscow, and elsewhere, fully testifies.

F. J.

Regulators for Electrical Distribution. By Georges Marié.

(Annales des Mines, vol. xiii., 1888, p. 1.)

The Author has previously, in the same journal, discussed generally the principles of regulators (November and December 1878), and in detail (September and October 1887) has shown the application of these principles to speed-regulators for prime movers, and to pressure-regulators for gas and water. In the present case these considerations are extended to regulators of electricity.

The methods of regulation at present used are applied to—(1) series-distribution with constant current; (2) simple parallel distribution at constant potential; (3) parallel distribution with feeders; (4) three-wire distribution, with and without feeders; (6) distribution by alternate currents, with transformers in parallel; (7) sundry methods, including accumulators and continuous-current motor transformers.

The methods of regulation are hand regulation, as used by Edison, automatic regulators acting on the engine, as used by Willans, Westinghouse, and Richardson, automatic regulators acting on the dynamo, as used by Brush, Zipernowsky, &c., and compound-wound self-regulating dynamos.

For small isolated plants, where the percentage variation in load is liable to be very large, compound-wound dynamos give the best results; for large installation or central stations where the

variation in load is not so rapid, hand regulation or automatic mechanical regulators are better, as compound dynamos give rise to trouble in coupling.

The regulation of electric motors may be effected by compound winding, if used on circuits of constant potential. If employed with constant currents, centrifugal or other governors must be used, which control the speed by cutting off the supply intermittently, or by inserting resistances. This form of governor should fulfil the following conditions. It ought to be possible (1) to alter the mean speed of the motor, without altering the sensibility of the governor; (2) to alter the sensibility without altering the mean speed. The Author gives an empirical rule to determine the proper relation which should exist between the kinetic energy of the moving parts and the power of the motor—

$$\tfrac{1}{2}\,M\,V^2 = 26\,\frac{K}{E},$$

Where $\tfrac{1}{2}\,M\,V^2$ = the kinetic energy of the armature, &c., K is the number of horse-power, and E is the ratio of the variation of speed to the mean speed.

If the supply, instead of being cut off entirely, is diminished by inserted resistances, the rule may be modified—

$$\tfrac{1}{2}\,M\,V^2 = 13\,\frac{K}{E}.$$

If the kinetic energy be expressed in foot-pounds and English horse-power, the numbers 26 and 13 become 190 and 95 respectively.

In the case of arc-lamps, the question of regulation resolves itself into (1) regulating with constant potential on the circuit, in which case a resistance must be added to the lamp circuit; or (2) constant current through the lamp. In the first case, lamps may be regulated by variation in the current through the lamp, by variation in the potential at the terminals of the lamp, or by differential lamps combining both. The second case can only be dealt with by regulating from the difference of potential at the terminals of the lamp, as, if the current is kept constant, differential lamps really regulate in the same way.

The Author describes in detail many well-known forms of regulators for engines, dynamos, motors, and lamps, some of these being illustrated.

LL. B. A.

Electric Street-Cars with Special Reference to Methods of Gearing. A. Reckenzaun.

(Transactions of the American Institute of Electrical Engineers, 1888, p. 2.)

The Author states, that of the dozen or so electric tramways in Europe, that of Frankfort, in Germany, is worked at the highest cost, and gives the annual working costs as follow:—

	£
Salaries—Directors, manager, engineers, electricians, conductors, drivers, firemen, labourers	3,200
Repairs to roadway, cars, machinery, and buildings . .	1,188
Fuel (coal and wood)	923
Oil and waste	195
Lighting and heating buildings, lighting cars and streets .	332
Total . . .	5,838

Taking an average of nine cars per day, the cost per car-day is 35*s.* 6*d.*, of which about one-third or 11*s.* 10*d.* is the cost of traction.

Various methods of gearing the motor to the driving-shafts have been devised. On the Berlin Lichterfeld tramway, Messrs. Siemens and Halske have adopted cast-iron pulleys on the motor-shaft, with twenty-seven V-grooves, in which run spiral cords of steel wire on the wheel-axles; larger-grooved drums receive the motion. This gearing is perfectly noiseless, but is not adapted to steep grades. Pitch chains have been tried, but without any great success, owing to wear and stretching. Mr. Volks' trams on Brighton beach are driven by linked leather belts, as ordinary leather belts proved unsuitable. One belt has run 50,000 miles; there are no steep grades to be overcome. Spur-gearing has been used at Frankfort, but not very successfully, the wear being excessive; but the Sprague Company in America, by taking great care, and using cut-wheels, has produced a noiseless and lasting gear. Friction-gears hitherto have failed. The Author has recently tried special worm-gears running in an oil bath, with excellent results, its efficiency being 81 to 87 per cent. Data of worm-gear: Steel worm polished, 6 inches in diameter, 6 inches long, treble thread 2 inches pitch, worm-wheel, phosphor-bronze, trimmed teeth, $15\frac{9}{32}$ inches in diameter, $3\frac{1}{2}$ inches across face, twenty-four teeth. Velocity ratio 8 to 1. A flexible coupling was used between the motor-shaft and worm-shaft. This worm will run either as a driver or when driven by the worm-wheel.

Ll. B. A.

Lightning-Arresters and the Photographic Study of Self-Induction. By E. G. Acheson.

(The Electrical Engineer, New York, 1889, p. 47.)

The motive for the experiments described in this Paper was the desire to determine the cause of occasional failures of underground conductors, which, though to all appearance properly protected by lightning-arresters, were frequently damaged, the insulation at the faults being found to be carbonized by an electric discharge. In the light, however, of Professor Lodge's experiments on the "alternative path," it seemed that the lightning-arresters of ordinary practice might be no protection at all; experiments were therefore conducted on a short piece of lead-covered cable, connected to a protector, the distance of the points of which were adjustable, and between which and the sheathing of the cable a wire of any required length could be introduced, a spark discharge from a Leyden jar being taken through the combined circuit, and the results diagrammatically exhibited. The Author's conclusions, as regards the theory of the subject, are, that the spark which will traverse a space of $\frac{1}{3}$ inch of air in preference to a 20-foot length of ordinary telegraph wire, is due, not to the air space presenting an equally easy path, but rather to the electrification of the wire, discharging in its turn through the air space, so that this spark is in reality a secondary effect of the original discharge. As regards their practical effects on the arrangement of lightning-arresters, they are summed up as follow:—

The wire connecting the earth plate of the arrester to "earth" must be as short as possible, and should preferably consist of a number of strands, not laid up into a cable; up to 40 inches in length this connection may be either of copper or iron, but for longer lengths iron is more suitable, as the resistance is of little consequence, provided the section is sufficient to carry off the discharge without overheating. The insulation of the cable may be punctured either by the direct discharge, a result of the points of the protector being too far apart, or by the current of self-induction from the "earth wire" of the arrester when that wire is of considerable length. In all cases when an over-head line is connected to a cable, a lightning-arrester should be attached to the sheathing of the cable by a connection not more than a few inches in length. Dissipation of the energy of discharge reduces the self-induced current, and consequently any method by which a portion of the discharged current which passes over the "earth wire" can be withdrawn will tend to increase the efficiency of the arrester.

He obtains a further confirmation of the Author's views by examination of photographs of these discharge sparks in the different experiments. The main discharge spark and the spark at the alternative path were arranged so that the light from them passed

in one straight line through a series of holes punched round the edge of a circular disk, which could be rapidly rotated in front of a sensitized plate, which would receive the light from one or perhaps two holes at any given moment of time. If the disk was rotating, and the sparks were synchronous, a simple defined picture of the hole would be the result on the negative; but if one spark is subsequent to the other, the images from the two sparks will not coincide. The examination of the plates reveals the fact that the spot is in each case followed by a ghostly elongation, showing a duration of the spark of rather less than one ten-thousandth of a second; but the absence of any displacement of the distinct outlines of the spot does not allow of any assumption of difference in time between the sparks, or measurable at least by this special arrangement of apparatus. In a discussion following this Paper, when it was read before the American Institute of Electrical Engineers, it was disclaimed that these effects could be the result of any photographic failure, *per se*, such as reflection from the glass negatives, &c., but must be ascribed to the oscillatory nature of the spark discharge.

F. J.

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MINUTES OF PROCEEDINGS,

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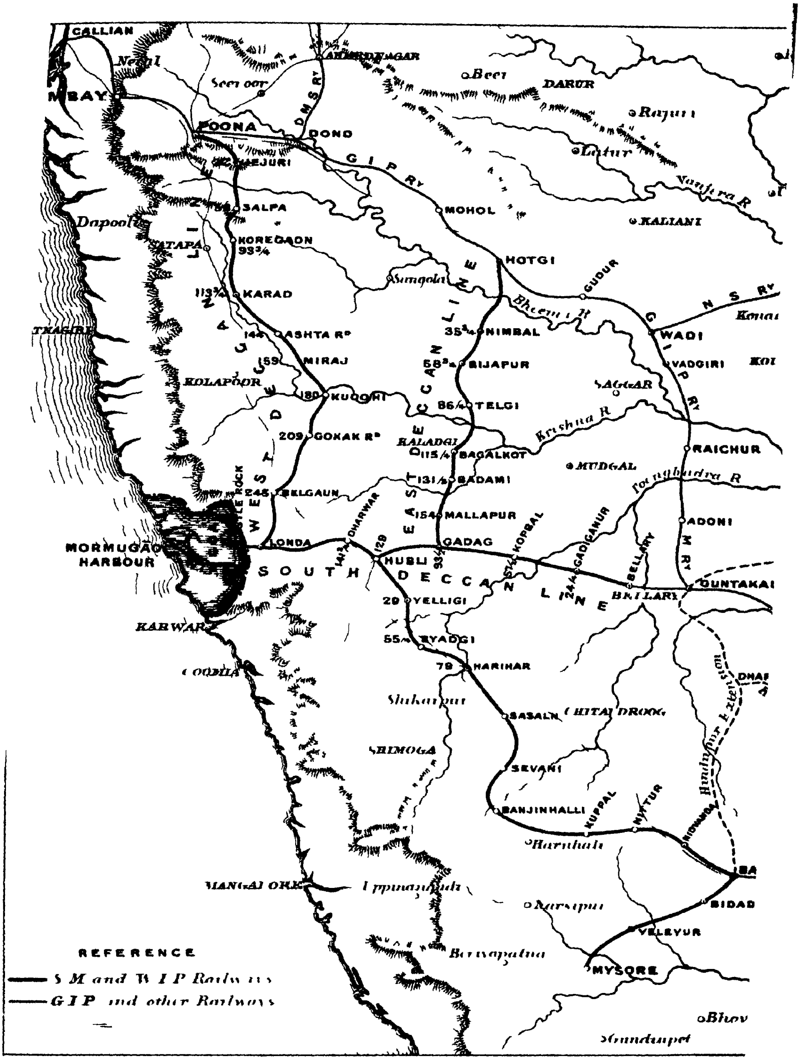

MAP OF THE SOUTHERN MARATHA AND W.I.P. RAILWAYS.

Scale 30 Miles = 1 Inch

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WEST OF INDIA PORTUGU

RAILWAY AND HARBOUR WORKS.

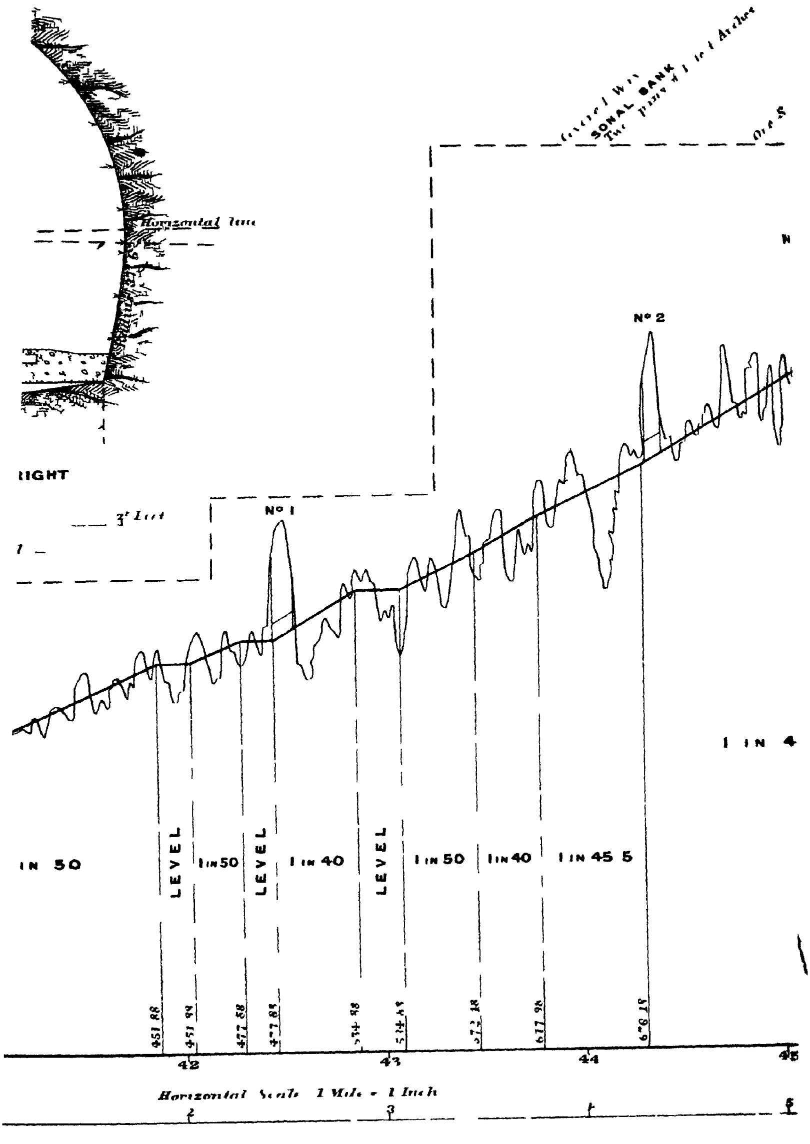

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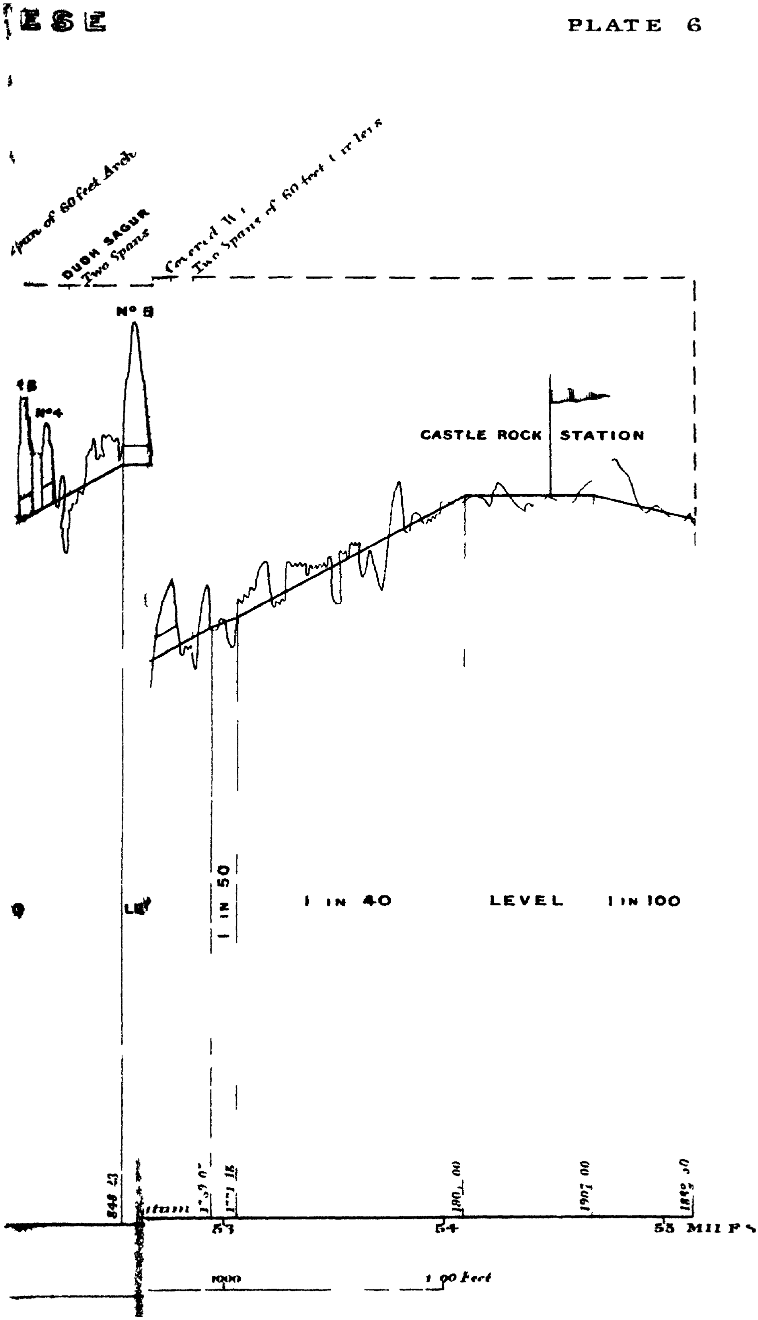
PLATE 6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DUDH SAGUR
Two Spans
Nº 5
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CASTLE ROCK STATION
1 IN 50
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848 23
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54
55 MILES
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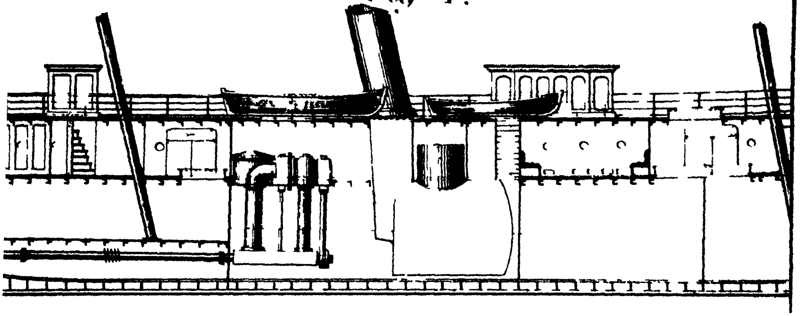
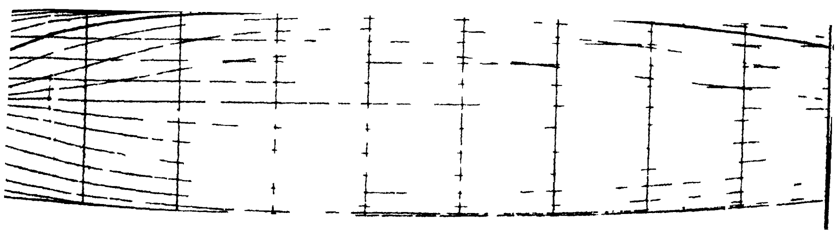
Fig. 1.





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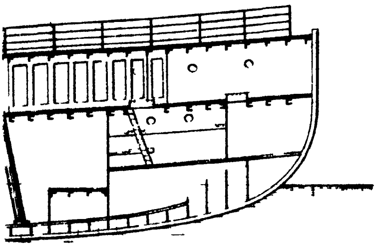
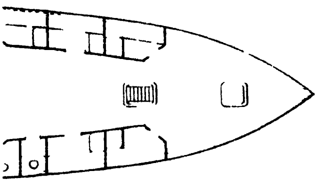
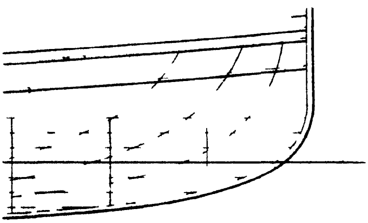
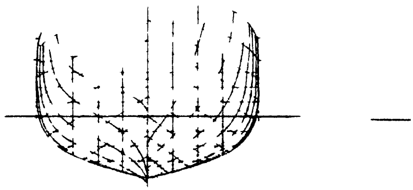
STEAMERS FOR WINTER NAVIGATION

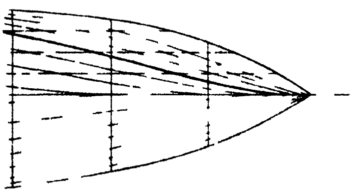




Length over all	190
Breadth	22 6
Draught of water	11 6
Displacement tons	15[illegible]
Ind. H.P.	400
Speed in knots	10







Scale of Feet

Fig: 1.

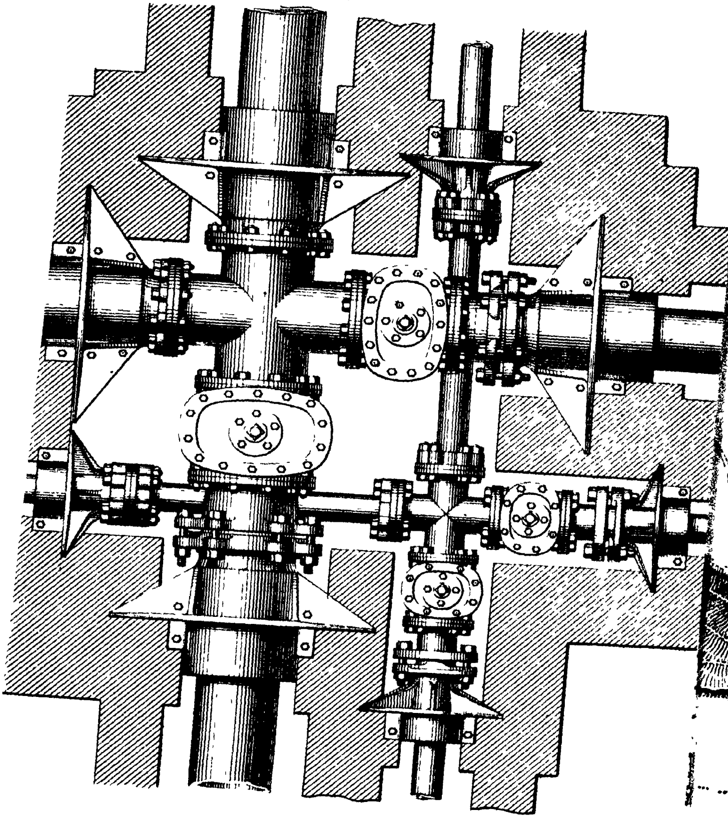
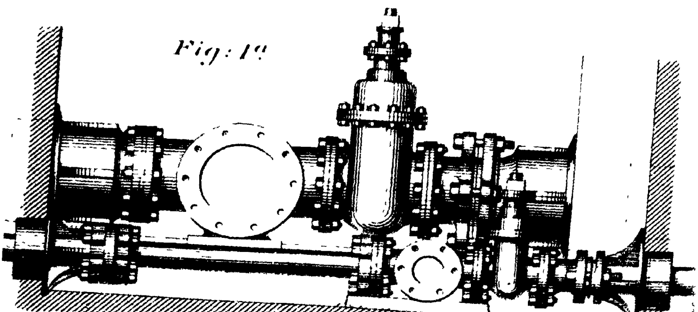


Fig: 1a



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IN THE UNITED STA

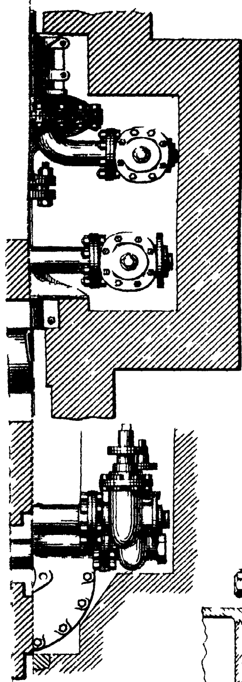


Fig 6

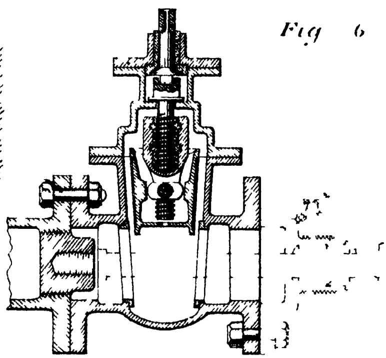


Fig 5

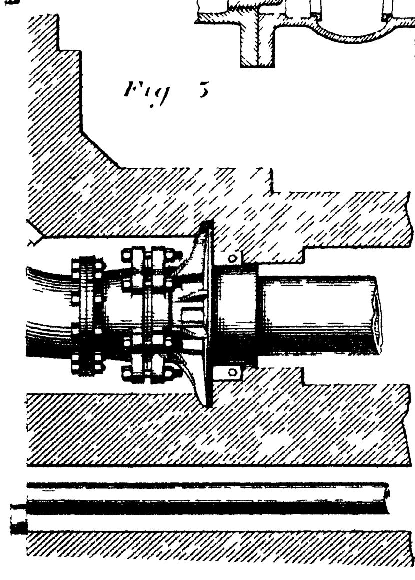


Fig 7

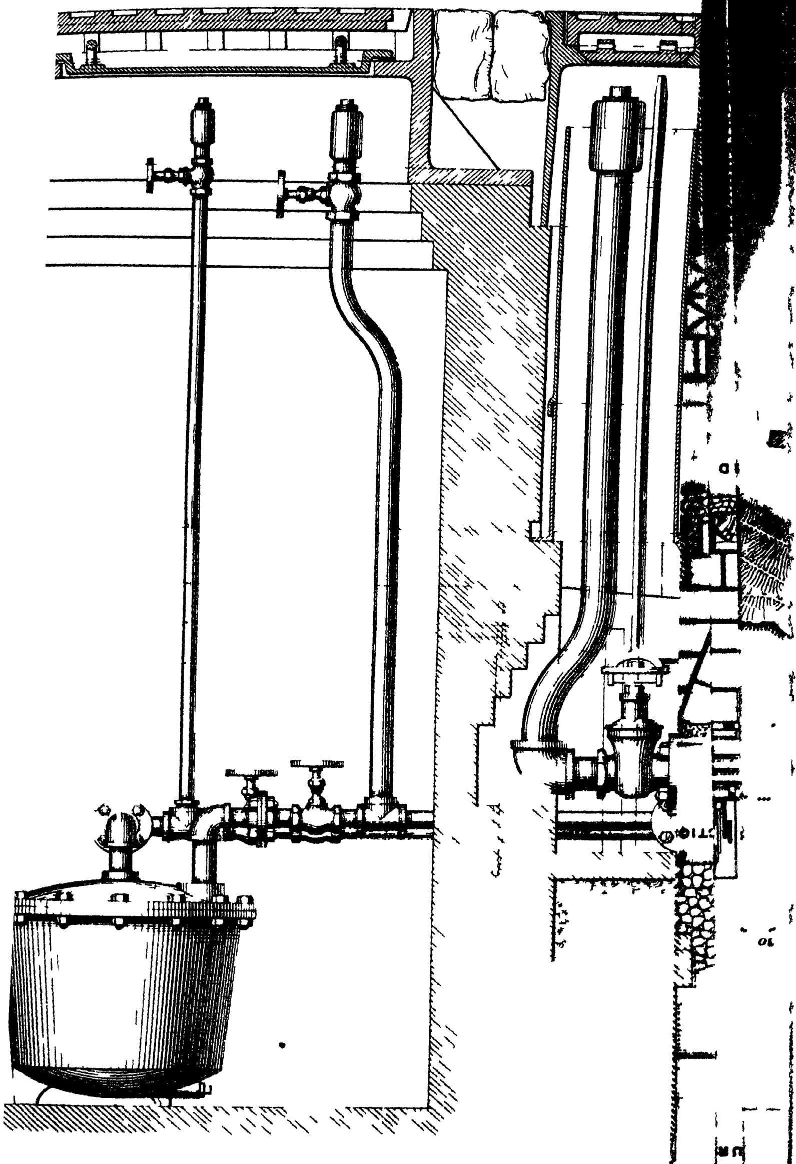


Fig. 8.

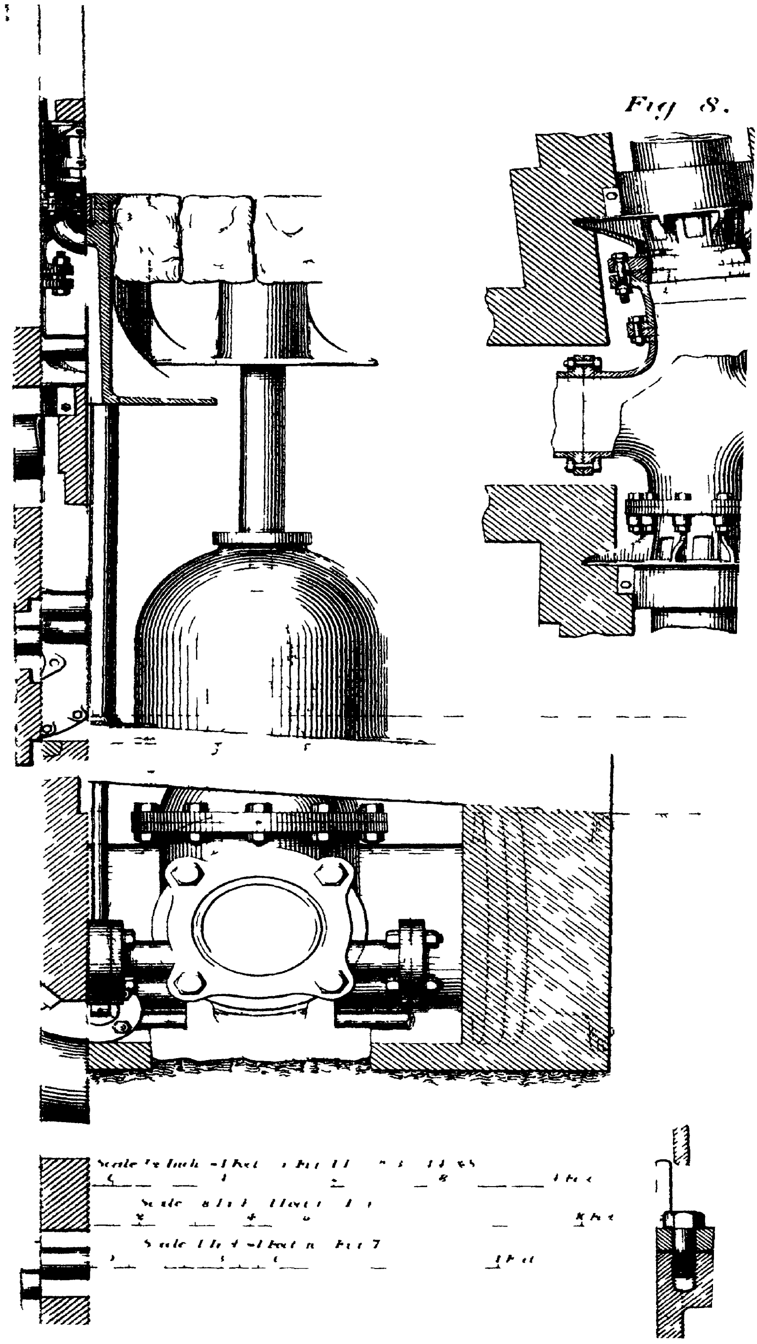
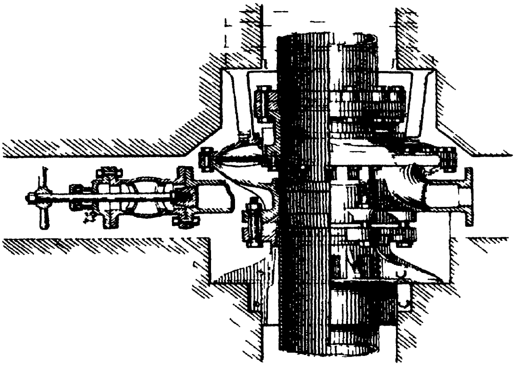


Fig 9



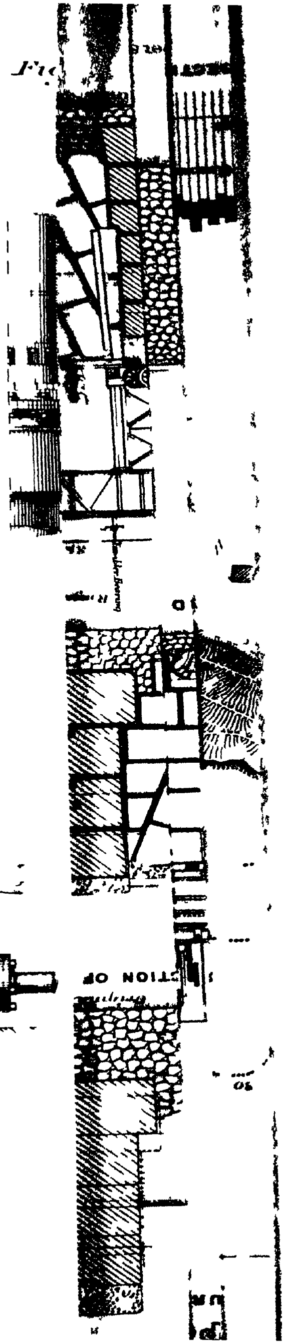


Fig 12

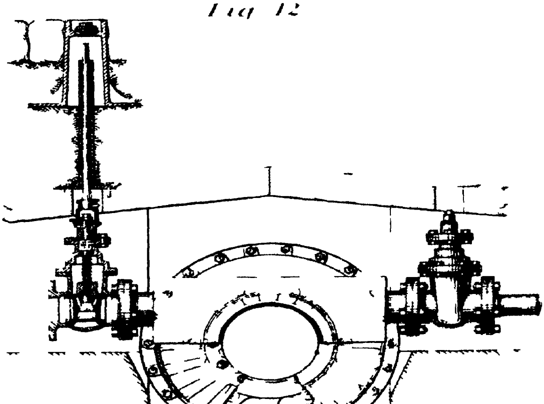
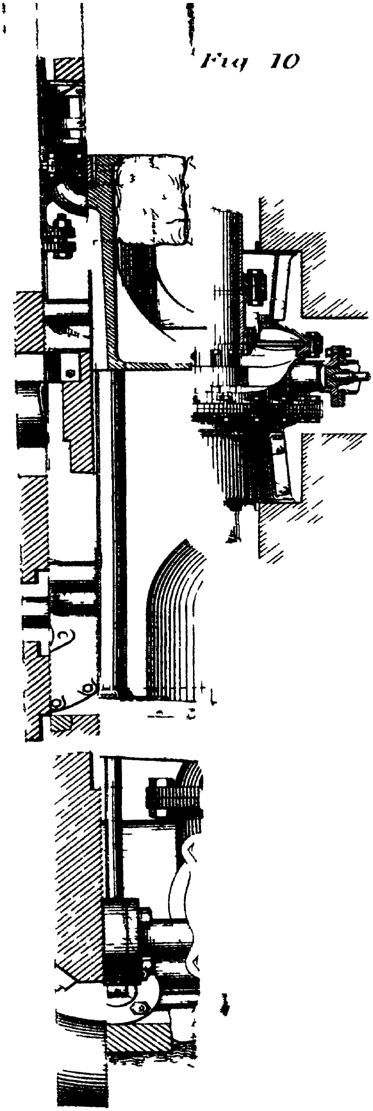


Fig 10



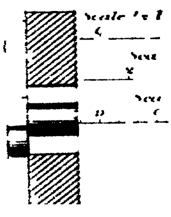


Fig 11^b

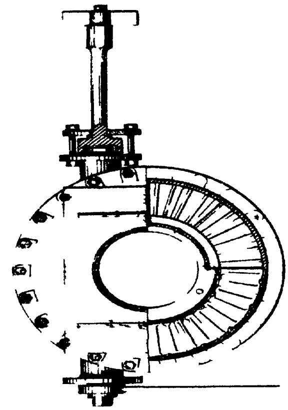
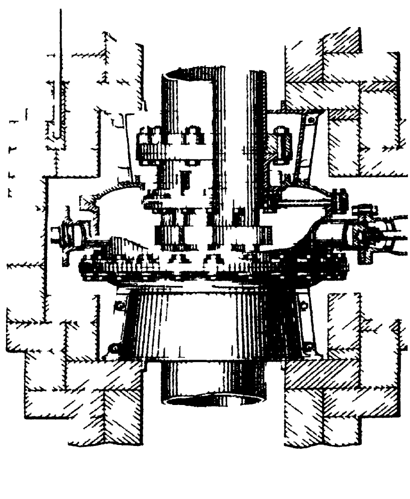
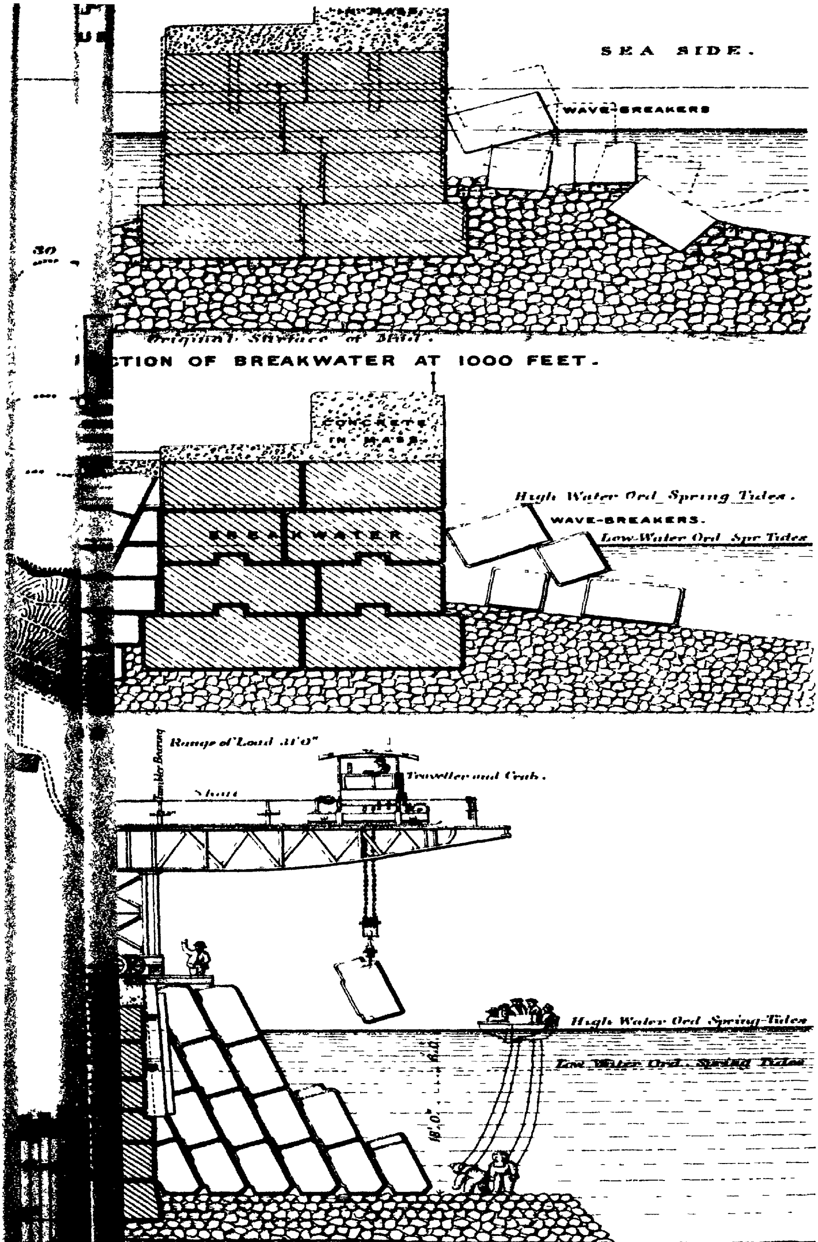
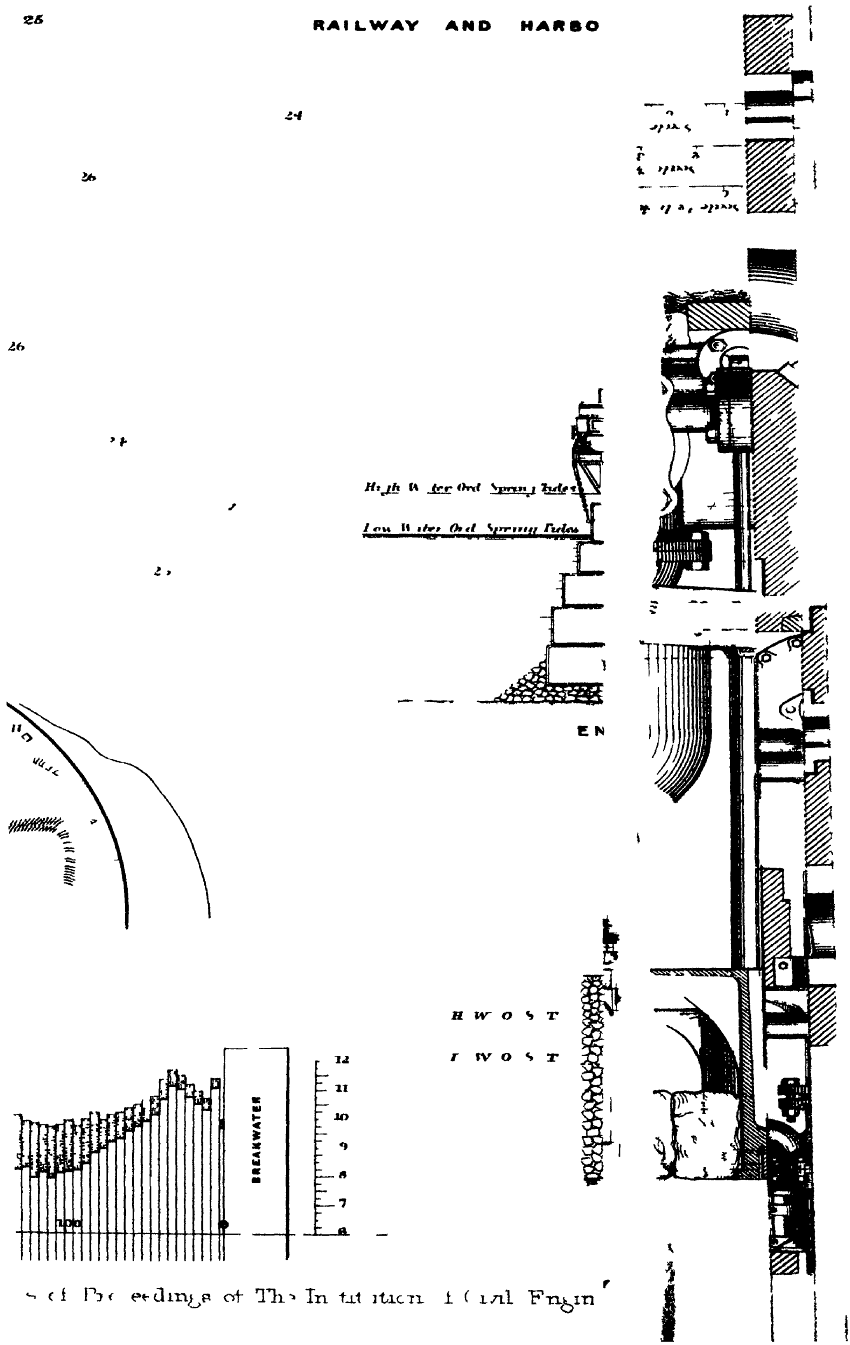


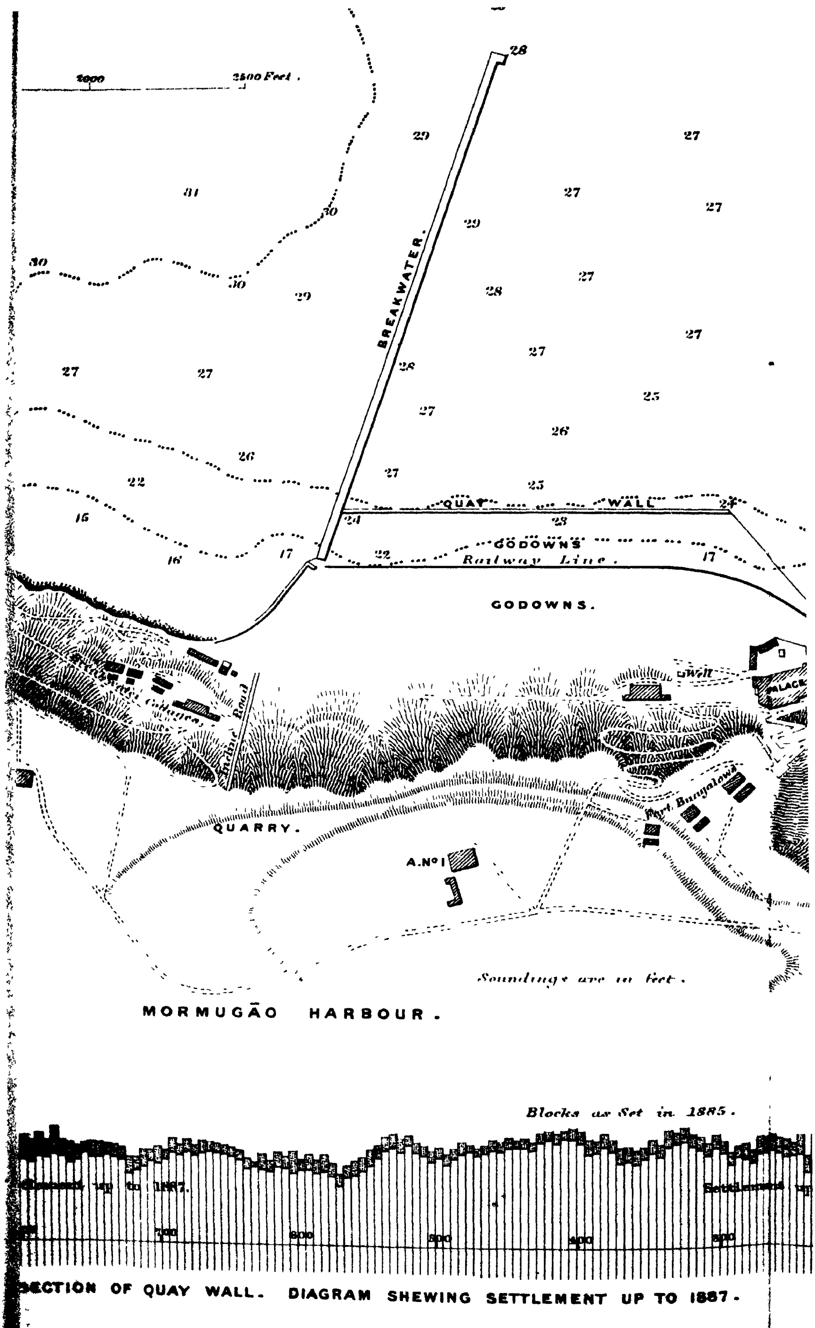
Fig 11

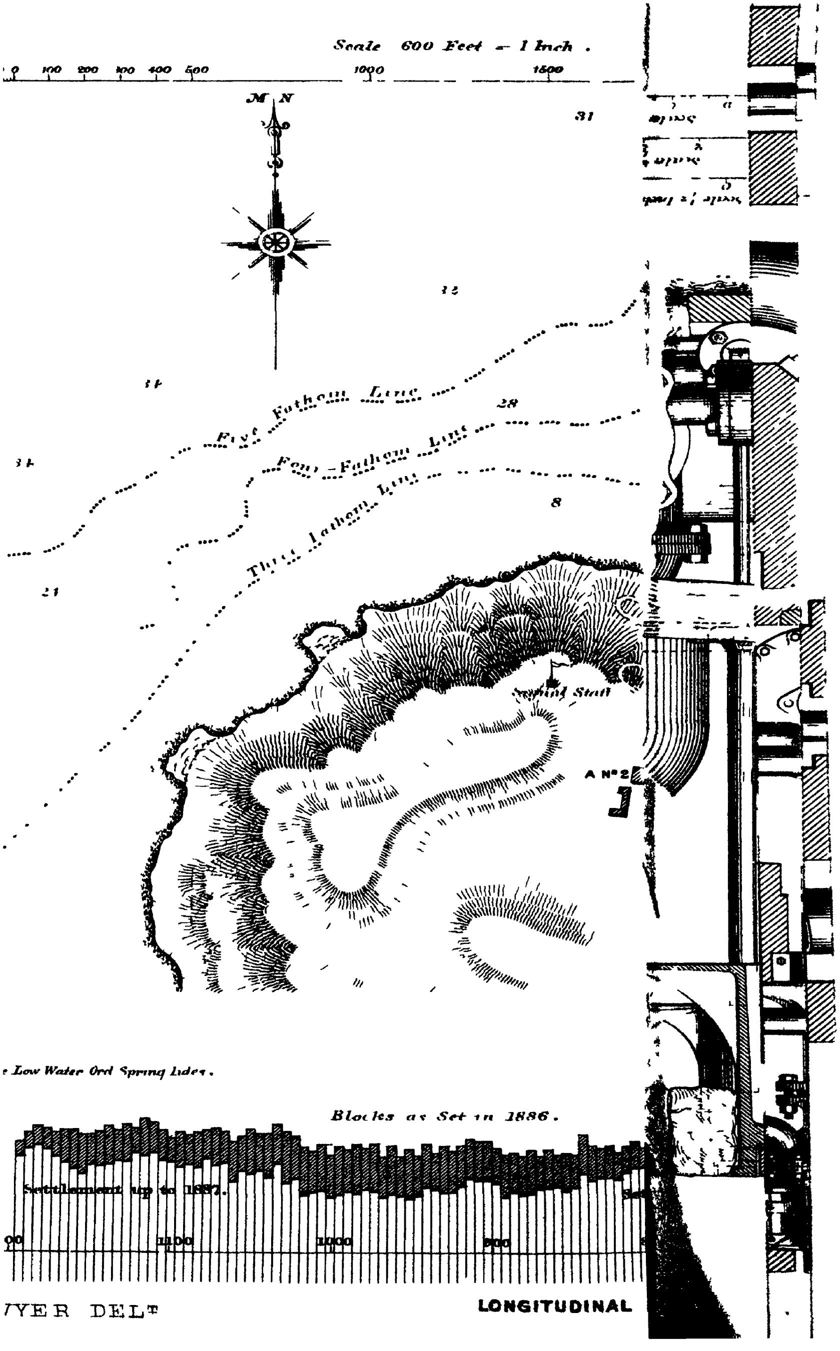




THOS KELL & SON LITH 40, KING ST COVENT GARDEN


High Water Ord Spring Tides
Low Water Ord Spring Tides
EN
HWOST
LWOST
BREAKWATER
100
12
11
10
9
8
7
6


2000
2500 Feet.
28
29
27
31
30
BREAKWATER.
QUAY WALL
GODOWNS
Railway Line.
GODOWNS.
Well
Incline Road
Fort Bungalows
QUARRY.
A. No 1
Soundings are in feet.
MORMUGÃO HARBOUR.
Blocks as Set in 1885.
Settlement up to 1887.
700
600
500
400
300
SECTION OF QUAY WALL. DIAGRAM SHEWING SETTLEMENT UP TO 1887.



Scale 600 Feet = 1 Inch .
0 100 200 300 400 500 1000 1500
M N
31
12
14
28
Five Fathom Line
Four Fathom Line
Three Fathom Line
8
21
Signal Staff
A Nº 2
Low Water Ord Spring Tides .
Blocks as Set in 1886 .
Settlement up to 1887.
1100
1000
900
YER DELT
LONGITUDINAL

Fig : 1.

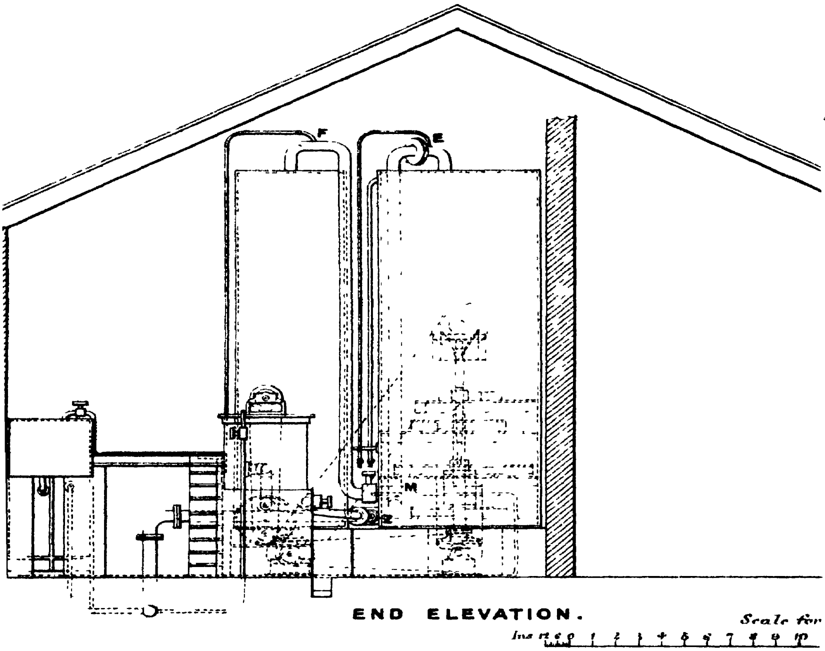
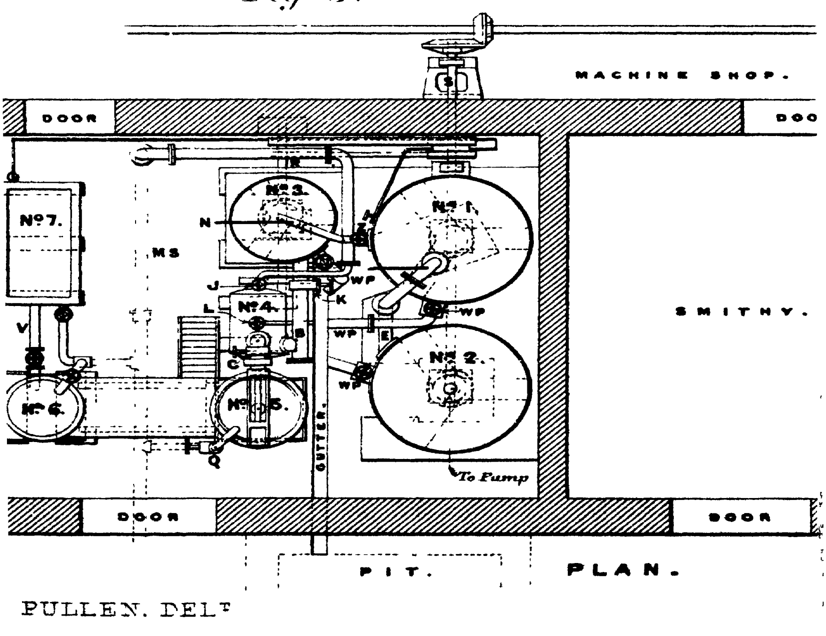
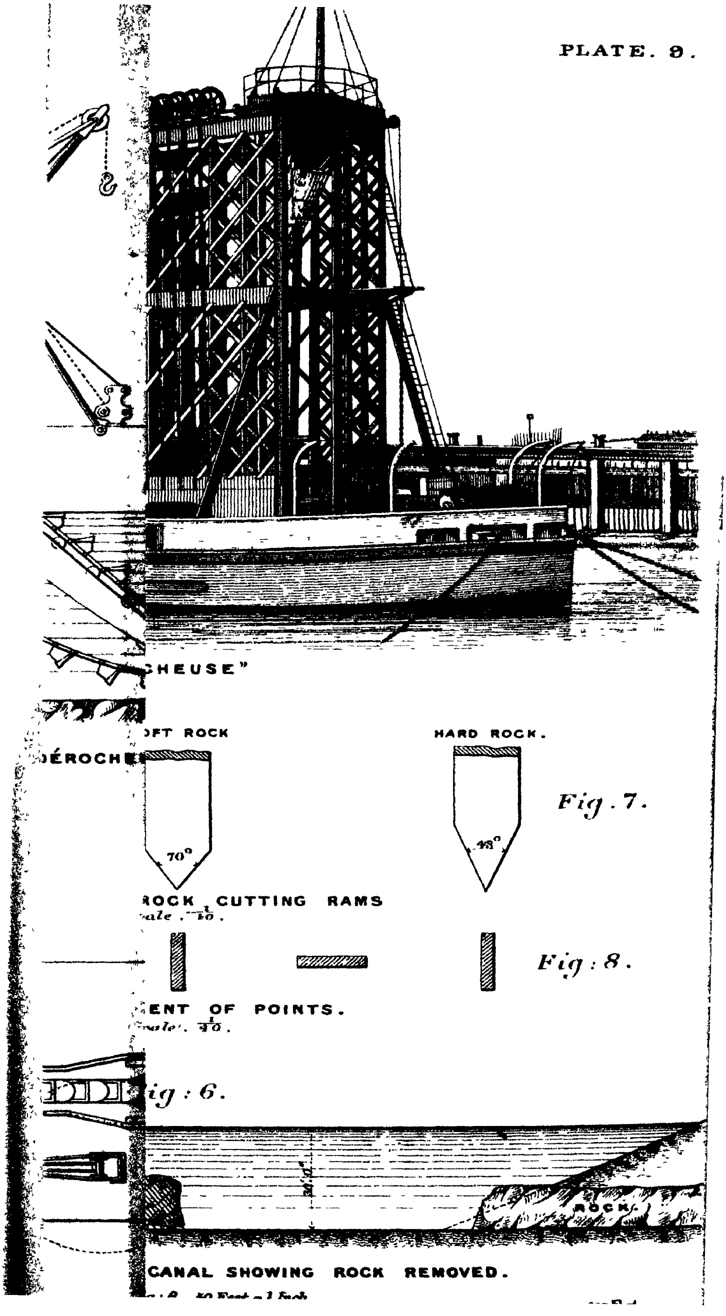


Fig · 3.



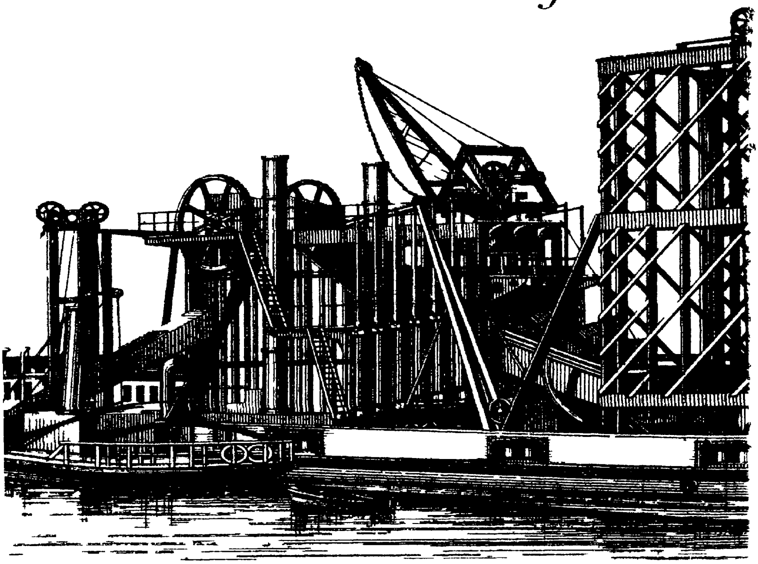
PULLEN. DELT

PLATE. 9.

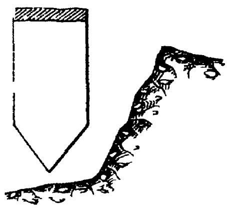

"HEUSE"
DÉROCHE
OFT ROCK
HARD ROCK.
70°
48°
Fig. 7.
ROCK CUTTING RAMS
Fig : 8.
ENT OF POINTS.
ig : 6.
ROCK
CANAL SHOWING ROCK REMOVED.

R WATER.

Fig 3.

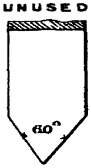


ROCK DREDGER "DÉRO



NGLOMERATE

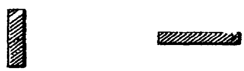
UNUSED



SC

POINTS OF F

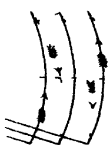
S



ARRANGEM

S

F



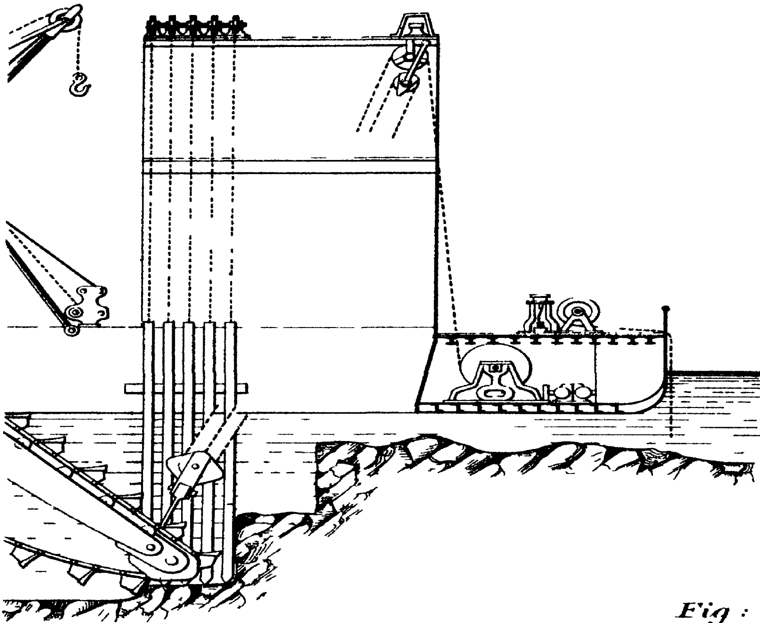
T SYSTEM

NG

SECTION OF ENLARGED

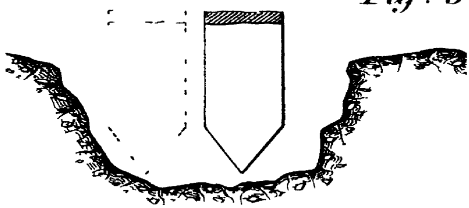
REMOVAL OF ROCK

WITHOUT EXI



)ÉROCHEUSE."

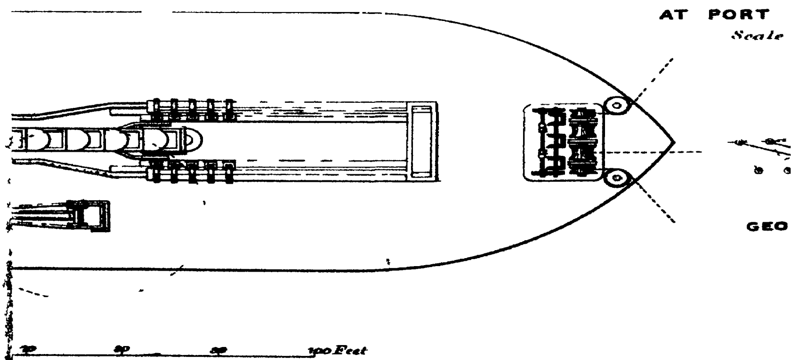
Fig : 5



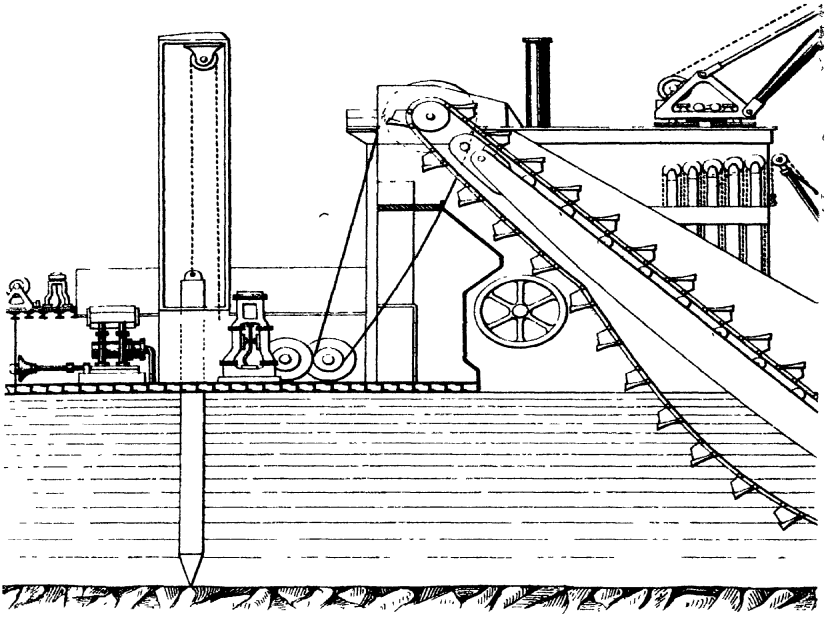
IRREGULAR EXCAVATING WITH

AT PORT

Scale

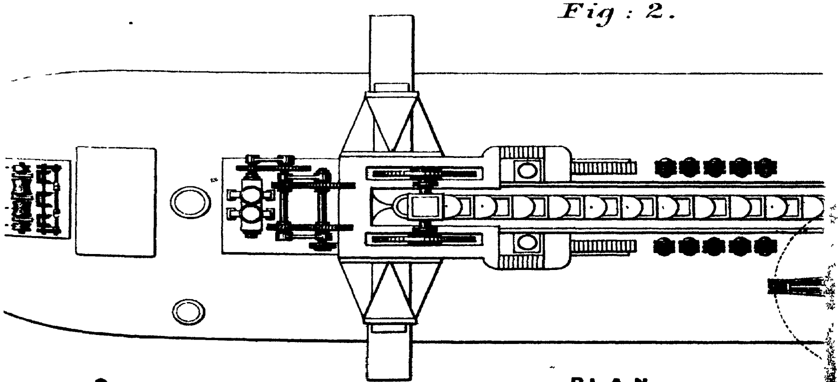


: 1.



LONGITUDINAL SECTION OF ROCK DREDGER

Fig : 2.



PLAN.

Scale for Fig^s 1 & 2, – 25 Feet – 1 Inch.

Feet 10 5 0 10 20 30 40 50 60

TZ, DEL^T